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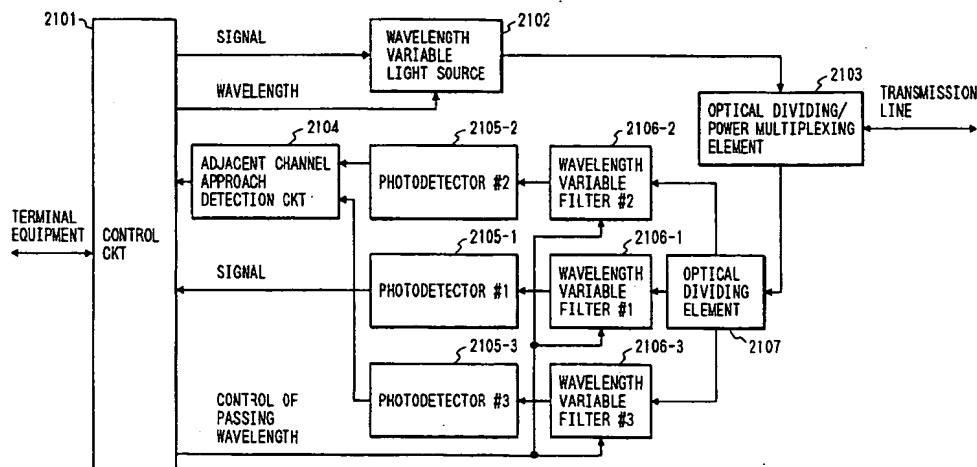
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(54) Wavelength control in a WDM system

(57) In a wavelength-multiplexing communication system, an optical transmitter detects at least either one wavelength of a transmission wavelength of a self optical transmitter and a wavelength adjacent to the transmission wavelength of the self optical transmitter on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter by a wavelength-var-

able band-pass filter capable of changing a passing wavelength thereof, and controls the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto may become a predetermined wavelength spacing.

FIG. 1
PRIOR ART



Description

BACKGROUND OF THE INVENTION5 Field of the Invention

The present invention relates to an optical communication system, and more particularly to an optical communication system for transmitting optical signals of a plurality of different wavelengths as wavelength-multiplexing them.

10 Related Background Art

The wavelength-multiplexing optical communication method is arranged to transmit optical signals of different wavelengths through a single transmission line, thereby improving a utilization factor of the transmission line. A system for the method is normally composed of a plurality of stations for transmitting the optical signals of different wavelengths, light superimposing means for guiding these optical signals into the single transmission line, the single transmission line, wavelength separating means for separating only a signal of a necessary wavelength out from a wavelength-multiplexed signal, and a plurality of stations receiving the multiplexed signal.

The system of this type mainly uses a semiconductor laser as a light source provided in each station, an optical fiber as the transmission line, an optical multiplexing element composed of a half mirror and light waveguides as the light superimposing means, and an optical wavelength filter as the wavelength separating means.

The semiconductor laser as a light source, however, has such a drawback that the wavelength of emitted light therefrom easily changes depending upon factors including the temperature etc. Thus, it has the following problems: (1) spacings between the wavelengths must be increased in order to avoid interference, which makes it difficult to raise multiplicity; (2) introduction of wavelength reference and precise temperature control is necessary for precise wavelength control, which makes the system complicated.

In order to solve these problems, communication methods without reference are proposed for example like the method as described in Japanese Laid-open Patent Application No. 3-214830.

Fig. 5 is a schematic drawing to show a system for achieving the wavelength-multiplexing optical communication method of the conventional example. In the drawing, reference numeral 301 designates an optical star coupler, 302-1 to 302-n optical fibers as being optical transmission lines, and 303-1 to 303-n terminal stations for optical communication.

Fig. 1 is a schematic drawing of an optical transmitter-receiver portion in each terminal station 303-1 to 303-n as shown in Fig. 5. In Fig. 1, reference numeral 2102 denotes a wavelength-variable light source such as a semiconductor laser capable of changing an oscillation wavelength by control from the outside, numeral 2103 an optical dividing / power multiplexing element for dividing signal light from the wavelength-variable light source 2102 into beams guided to the transmission line and to an optical dividing element 2107 and transmitting the wavelength-multiplexed light from the transmission line to the optical dividing element 2107, numeral 2107 the optical dividing element for distributing the light from the optical dividing / power multiplexing element to wavelength-variable filters 2106-1 to 2106-3, numeral 2104 a circuit for extracting necessary information from photodetectors 2105-2, 2105-3, numeral 2101 a control circuit for sending or receiving data to or from terminal equipment and controlling the wavelength-variable light source 2102 and wavelength-variable filters 2106-1 to 2106-3 in order to avoid interference with another station, numerals 2106-1 to 2106-3 the wavelength-variable filters whose wavelength regions of transmitted light can be changed by external control, and numerals 2105-1 to 2105-3 the photodetectors.

Fig. 2 is a drawing to show a relative relation among passing wavelengths of the wavelength-variable filters 2106-1 to 2106-3 as shown in Fig. 1. In the drawing, 2201 to 2203 indicate wavelength transmitting or passing characteristics of the respective wavelength-variable filters 2106-1 to 2106-3.

These wavelength-variable filters are arranged in such a manner that when external control changes the passing wavelengths, the three passing characteristics simultaneously change by a same wavelength and in a same direction while maintaining the relative relation among the passing characteristics.

Next explained is the operation of the conventional example having the above arrangement. For simplicity, let us use an example where communication is made using light of wavelength λ_1 from the terminal station 303-1 to the terminal station 303-2 in Fig. 5 and light of wavelength λ_2 from the terminal station 303-3 to the terminal station 303-n.

Let us suppose herein that the wavelength λ_1 and wavelength λ_2 are proximal to each other but apart more than the wavelength width necessary for communication from each other, thus not causing interference.

In the optical transmitter-receiver in the terminal station 303-1 shown in Fig. 1, the optical dividing / power multiplexing element 2103 sends part of the signal light of wavelength λ_1 from the wavelength-variable light source 2102 out to the transmission line to be transmitted to the terminal station 303-2. The rest is transmitted to the optical dividing element 2107 to be divided into three beams, which reach the wavelength-variable filters #1 (2106-1), #2 (2106-2), #3 (2106-3). The wavelength-variable filter #1 (2106-1) is controlled by a control signal from the control circuit 2101 so that the center of the passing wavelength thereof may be coincident with the wavelength λ_1 . Thus, the photodetector #1 (2105-1) sup-

plies a large output. The photodetectors #2 (2105-2), #3 (2105-3) supply outputs associated with response amplitudes to the wavelength λ_1 , of the wavelength-variable filters #2 (2105-2), #3 (2105-3).

In the optical transmitter-receiver in the terminal station 303-2 on the other hand, light of the wavelengths λ_1 , λ_2 coming through the transmission line passes the optical dividing / power multiplexing element 2103 and the optical dividing element 2107 to reach the wavelength-variable filters #1 (2106-1), #2 (2106-2), #3 (2106-3). Since the wavelength-variable filter #1 (2106-1) is controlled so that the center of the passing wavelength thereof may match with the wavelength λ_1 , the light of wavelength λ_2 is interrupted here, and only the light of wavelength λ_1 is converted into an electric signal by the photodetector #1 (2106-1). Then the electric signal is transmitted through the control circuit 2101 to the terminal equipment.

As described above, the semiconductor laser is used as the wavelength-variable light source 2102, and the oscillation wavelength thereof easily changes depending upon the temperature. Then here is explained the operation in the case where the wavelength changes so that the signal of wavelength λ_2 sent from the terminal station 303-3 approaches the wavelength λ_1 .

When the light of wavelength λ_2 comes into the passing band of the wavelength-variable filter #2 (2106-2), the output from the photodetector #2 (2105-2) increases. In contrast with it, the output from the photodetector #3 (2105-3) shows no change. Thus, an adjacent channel approach detection circuit 2104 can detect approach of light of a wavelength shorter than the wavelength λ_1 by checking the outputs from the two photodetectors. The adjacent channel approach detection circuit 2104 transfers this information detected to the control circuit 2101.

In accordance with this information detected the control circuit 2101 uses a control signal of passing wavelength to effect such control as to continuously move the wavelength of the wavelength-variable light source 2102 to longer wavelengths than λ_1 and thereby to avoid interference of signal with the wavelength λ_2 approaching. At the same time as it, the control circuit 2101 performs such control that the wavelength λ_1 after moved may become coincident with the passing center wavelength of the wavelength-variable filter #1 (2106-1), using control signals of passing wavelengths of the wavelength-variable filters #1 (2106-1), #2 (2106-2), #3 (2106-3).

In response to the operation that the terminal station 303-1 moved the wavelength λ_1 in order to avoid interference, the terminal station 303-2 receiving the signal of wavelength λ_1 experiences a decrease in the output signal from the photodetector thereof #1 (2105-1). Then, using a control signal of passing wavelength, the control circuit 2101 in the terminal station 303-2 controls the center of passing wavelength of the wavelength-variable filter #1 (2106-1) so as always to maximize the output signal from the photodetector #1 (2105-1). This operation permits the terminal station 303-1 to prevent interference when the output wavelength from the terminal station 303-3 changes to approach the output wavelength of the terminal station 303-1. At the same time, the terminal station 303-2 can continuously receive the signal from the terminal station 303-1 without being out of tuning.

The above function is also effective to the cases where the wavelength λ_2 approaches the wavelength λ_1 from the longer wavelength region, where only λ_1 changes while λ_2 is fixed, and where both λ_1 , λ_2 change, whereby communication can continuously be maintained as avoiding interference.

In the method as discussed above, the signals from the respective stations are scattered on the wavelength axis as guaranteed not to interfere with each other. There was, however, no positive device given to increase the wavelength multiplicity in order to improve the utilization factor of the usable wavelength region.

Further, the arrangement using the wavelength filters required three wavelength-variable band-pass filters upon transmission.

SUMMARY OF THE INVENTION

An object of the present invention is to realize wavelength control without use of reference wavelength or precise wavelength stabilizing control and to improve the wavelength multiplicity. Another object is not to increase a number of necessary filters and not to use a large-scale detection unit as used in heterodyne detection or homodyne detection. The present invention provides the following transmission wavelength control method to achieve the objects.

A transmission wavelength control method in an optical transmitter used in an optical communication system for performing wavelength-multiplexing communication, comprising a step of: in a transmission state,

detecting at least either one of a transmission wavelength of a self optical transmitter and a wavelength adjacent to the transmission wavelength of the self optical transmitter on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter, and controlling the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto may become a predetermined wavelength spacing,

wherein the detecting of wavelength is carried out using a wavelength-variable band-pass filter capable of sweeping a passing wavelength thereof.

There are the following embodiments of the transmitter:

wherein the detecting at least either one wavelength of the transmission wavelength of the self optical transmitter

and the wavelength adjacent thereto is carried out using a common wavelength-variable band-pass filter;

wherein in a steady state in which the wavelength spacing is controlled at the predetermined wavelength spacing and in one sweep step of the wavelength-variable filter, the both wavelengths of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto are detected;

wherein during a period of approaching a steady state in which the wavelength spacing is controlled at the predetermined wavelength spacing and in one sweep step of the wavelength-variable filter, the both wavelengths of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto are detected;

wherein during a period of approaching a steady state in which the wavelength spacing is controlled at the predetermined wavelength spacing and in one sweep step of the wavelength-variable filter, either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto is detected;

wherein upon detecting at least either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto using the wavelength-variable band-pass filter, either a sweep step of gradually increasing the passing wavelength of the wavelength-variable band-pass filter or a sweep step of gradually decreasing the passing wavelength is repeated;

wherein upon detecting at least either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto using the wavelength-variable band-pass filter, sweep steps of gradually increasing and gradually decreasing the passing wavelength of the wavelength-variable band-pass filter are alternately repeated;

wherein separate wavelength-variable band-pass filters are used each in detecting the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto;

wherein a spacing between passing wavelengths of the respective, separate, wavelength-variable band-pass filters is the predetermined wavelength spacing;

wherein the controlling step comprises in a period of approaching a steady state in which the wavelength spacing is controlled at the predetermined wavelength spacing,

a step of making either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto coincide with a passing wavelength of either one wavelength-variable band-pass filter out of the separate wavelength-variable band-pass filters; and

a step of controlling the transmission wavelength of the self optical transmitter as maintaining the coincident state, to move the transmission wavelength on the wavelength axis, thereby making the other wavelength out of the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto coincide with the transmission wavelength of the other wavelength-variable band-pass filter out of the separate wavelength-variable band-pass filters;

wherein the controlling step comprises a step of, in the steady state in which the wavelength spacing is controlled at the predetermined wavelength spacing, maintaining a state in which the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto are coincident with the respective passing wavelengths of the separate wavelength-variable band-pass filters;

wherein in order to maintain the state in which the wavelengths on the wavelength axis are coincident with the passing wavelengths of the wavelength-variable band-pass filters, the wavelength-variable band-pass filters are controlled by analog control;

wherein the wavelength-variable band-pass filters are subjected to feedback control by the wobbling method;

wherein in order to maintain the state in which the wavelengths on the wavelength axis are coincident with the passing wavelengths of the wavelength-variable band-pass filters, the wavelength-variable band-pass filters are controlled by digital control;

wherein the wavelength-variable band-pass filters are subjected to feedback control by digital control; further comprising

a step of setting a transmission start region at an end portion on an opposite side to either the longer wavelength side or the shorter wavelength side, in a wavelength region in which the self optical transmitter can perform transmission, starting the transmission in the transmission start region upon start of transmission, and interrupting the transmission when the wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto in the transmission start region becomes the predetermined wavelength spacing;

further comprising

a step of, upon start of transmission, starting the transmission after confirming that there is no other wavelength at least in the predetermined wavelength spacing at the end portion on the opposite side to either the longer wavelength side or the shorter wavelength side, in the wavelength region where the self optical transmitter can perform transmission.

Further, the present invention provides the following optical communication method.

An optical communication method in an optical communication system for performing wavelength-multiplexing communication by connecting a plurality of terminal stations each having their own optical transmitters, comprising a step of:

using the transmission wavelength control method of either one of the above methods, in an optical transmitter of a terminal station in a communication state;

whereby transmission wavelengths of the optical transmitters of the plural terminal stations are wavelength-multiplexed in order of transmission starts from either the longer wavelength side or the shorter wavelength side.

Further, the present invention also provides the following optical transmitter.

An optical transmitter used in an optical communication system for performing wavelength-multiplexing communication, comprising:

transmission means arranged as capable of changing a transmission wavelength;

wavelength detecting means capable of detecting the transmission wavelength of the self optical transmitter and a wavelength adjacent thereto on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter; and

means for, in a transmission state, controlling the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto may become a predetermined wavelength spacing, based on a result obtained when the wavelength-variable band-pass filter detects at least either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent to the transmission wavelength of the self optical transmitter on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter;

wherein the wavelength detecting means is a wavelength-variable band-pass filter capable of sweeping a passing wavelength thereof.

There are the following embodiments of the optical transmitter:

wherein the wavelength-variable band-pass filter is one wavelength-variable band-pass filter, the one wavelength-variable band-pass filter detecting the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter;

wherein the wavelength-variable band-pass filter is two wavelength-variable band-pass filters, the two separate wavelength-variable band-pass filters each detecting the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter.

Further, the present invention also provides an optical transmitter-receiver apparatus obtained by adding to the above optical transmitter an optical receiver comprising:

receiving means for receiving a light signal to be received by the self optical transmitter-receiver apparatus from a light signal input thereinto as following up a change in a wavelength of the light signal.

Further, the present invention also provides an optical communication system using either the above optical transmitter or optical transmitter-receiver apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a structural drawing of an optical transmitter-receiver in a terminal station in the conventional example prior to the present invention;

Fig. 2 is a drawing to show a relation among passing wavelengths of the wavelength-variable filters in the conventional example prior to the present invention;

Fig. 3 is a structural drawing of an optical transmitter in Embodiment 1;

Fig. 4 is a structural drawing of control circuit 101 in the optical transmitter in Embodiment 1;

Fig. 5 is a schematic drawing of an optical communication system in Embodiment 1;

Fig. 6 is a schematic drawing of an optical transmitter-receiver portion in a terminal station in the optical communication system in Embodiment 1;

Figs. 7A to 7D are drawings to illustrate control of transmission wavelength of each station in Embodiments 1 and 2;

Figs. 8A and 8B are drawings to illustrate the operation of control circuit 101 in Embodiment 1;

Fig. 9 is a drawing to illustrate control of transmission wavelength of each station in the present invention;

Figs. 10A and 10B are drawings to illustrate the operation of control circuit 101 in Embodiment 2;

Figs. 11A to 11D are drawings to illustrate control of transmission wavelength of each station in Embodiment 3;

Figs. 12A and 12B are drawings to illustrate the operation of control circuit 101 in Embodiment 3;

Figs. 13A to 13D are drawings to illustrate the operation of control circuit 101 in Embodiment 4;

Figs. 14A and 14B are drawings to illustrate control of transmission wavelength of each station in Embodiment 4;

Fig. 15 is a structural drawing of the optical transmitter in the fifth embodiment of the present invention;

Fig. 16 is a structural drawing of control circuit 1301 in the fifth embodiment of the present invention;

Fig. 17 is a drawing to show a relation between the passing wavelength of the wavelength-variable filter shown in

Figs. 13A to 13D and the wavelength of output light from the wavelength-variable light source;

Figs. 18A to 18C are drawings to illustrate the operation of the wavelength-variable light source and wavelength-variable filters in the transmitter of each terminal station in the fifth embodiment of the present invention;

Fig. 19 is a drawing to illustrate control of transmission wavelength of each terminal in the fifth embodiment of the present invention;

Fig. 20 is a structural drawing of control circuit 1301 in the sixth embodiment of the present invention;
 Figs. 21A to 21C are drawings to illustrate the operation of control circuit 1301 in the sixth embodiment of the present invention; and
 Fig. 22 is a drawing to illustrate the operation of ON/OFF control circuit 1408 in the control circuit 1301 in the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(Embodiment 1)

The first embodiment of the present invention will be explained with reference to the drawings.

Fig. 3 is a structural drawing of a wavelength control system in the transmitter of the present invention.

Reference numeral 101 designates a control circuit, which controls an output wavelength of a wavelength-variable light source 103 and a passing wavelength of a wavelength-variable band-pass filter (hereinafter referred to as a wavelength-variable filter) 105. Numeral 102-1 denotes a drive circuit, which drives the wavelength-variable light source 103, based on a signal from the control circuit 101. This light source is arranged so that the wavelength of output light therefrom can be changed by control from the outside, for example like a semiconductor laser. Further, for example the intensity of the output light can be modulated according to a transmission signal from the outside. Numeral 104 is an optical dividing / power multiplexing element, which outputs the output light from the wavelength-variable light source 103 into a transmission line and which outputs received light through the transmission line to the wavelength-variable filter 105. Numeral 105 is the wavelength-variable filter, which is a filter that can change the wavelength region of transmitted light by external control, for example such as a fiber Fabry-Perot filter. Numeral 106 represents a light receiving element, which receives the light emitted from the wavelength-variable light source 103 and then transmitted by the wavelength-variable filter 105. Numeral 107 denotes an amplifier, which amplifies a signal from the light receiving element 106 to output the amplified signal to the control circuit 101. Numeral 102-2 stands for a drive circuit, which drives the wavelength-variable filter 105, based on a signal from the control circuit 101.

In the above configuration, the optical dividing / power multiplexing element 104 is constructed for example of a half mirror or a beam splitter.

Further, the wavelength-variable light source 103 can be realized for example by a semiconductor laser of the DBR type. This is a semiconductor laser having a structure that can continuously change the oscillation wavelength by injecting carriers into a region of DBR (distributed Bragg reflector) to change the Bragg wavelength thereof. A specific example of the wavelength-variable light source 103 is the one as described in K. KOTANI, M. MATSUDA, M. YANO, H. ISIKAWA, and H. IMAI, Electronics Letters vol. 23, No. 7, p325-p327, 1987.

In the present invention the wavelength-variable light source 103 is composed of a wavelength adjusting section for changing the wavelength of the output light thereof and an output light modulating section for modulating the output light. In the case of the wavelength-variable DBR semiconductor laser, the DBR portion corresponds to the wavelength adjusting section and the active region to the output light modulating section. In the present embodiment the drive circuit 102-1 is connected to the wavelength adjusting section. The output light modulating section receives a transmission signal from the transmitter of its own station (the self station) to modulate the intensity of the output light.

A specific example of the wavelength-variable filter 105 is an FFP (fiber Fabry-Perot) type filter. This filter is constructed in such a manner that two optical fibers are opposed at the end faces thereof to each other to form an FP (Fabry-Perot) resonator and a distance between the end faces (that is, the resonator length) can finely be adjusted by a piezoelectric device. By changing the resonator length, the passing wavelength of the filter can be changed. A specific example of this wavelength-variable filter is the one constructed as described in J. STONE and L. W. STULTS, Electronics Letters vol. 23, No. 15, p781-p783, 1987.

As input voltages into the drive circuits 102-1 and 102-2 increase, the wavelength of the wavelength-variable light source 103 and the passing wavelength of the wavelength-variable filter 105 each change to longer wavelengths in this example.

Fig. 4 is a drawing to show a setup of the control circuit 101 shown in Fig. 3.

Numeral 201 designates a CPU, which receives a control signal from the terminal equipment, receives data from an A/D converter 203, and sends data to D/A converters 202-1 and 202-2 after completion of necessary calculation. Numeral 202-1 represents a D/A converter, which outputs a control signal to determine the transmission wavelength of the wavelength-variable light source 103 to the drive circuit 102-1, based on the data from the CPU 201. Numeral 202-2 represents a D/A converter, which outputs a control signal to determine the passing wavelength of the wavelength-variable filter 105 to the drive circuit 102-2, based on the data from the CPU 201. Numeral 203 denotes an A/D converter, which converts a signal obtained from the amplifier 107 into numerical data and outputs it to the CPU 201.

Fig. 5 is a schematic drawing to show a system for achieving the wavelength-multiplexing optical communication method of the present embodiment. In the drawing, numeral 301 is an optical star coupler, 302-1 to 302-n are optical fibers as being optical transmission lines, and 303-1 to 303-n are terminal stations for optical communication.

Fig. 6 is a schematic drawing of the optical transmitter-receiver portion of each terminal station 302-1 to 302-n shown in Fig. 5. In the drawing, numeral 401 stands for an optical dividing / power multiplexing element, 402 for a transmitter, and 403 for a receiver.

Figs. 7A to 7D are drawings to show relations on the wavelength axis between communication wavelengths and the passing wavelength of the wavelength filter where there are a plurality of stations communicating by the present method. In the drawings, λ_1 to λ_{k-1} represent transmission wavelengths of other stations, λ_k a transmission wavelength of a self station, λ_{f1} a sweep start wavelength of the wavelength-variable filter 105 in the self station, λ_{f2} a sweep end wavelength thereof, $\Delta\lambda_a$ and $\Delta\lambda_b$ margins upon sweep of passing wavelength, $\Delta\lambda_c$ a wavelength spacing between λ_k and λ_{k-1} , $\Delta\lambda_{c0}$ a predetermined value for the wavelength spacing $\Delta\lambda_c$, and $\Delta\lambda_d$ a moving amount of λ_k . Fig. 7A and Fig. 7B show cases where $\Delta\lambda_c$ is greater than the predetermined value $\Delta\lambda_{c0}$, Fig. 7C a case where they are equal to each other, and Fig. 7D a case where $\Delta\lambda_c$ is smaller than the predetermined value $\Delta\lambda_{c0}$. Here, $\Delta\lambda_{c0}$ as the predetermined spacing is a clearance necessary for avoiding interference between λ_k and λ_{k-1} and is a constant value. This predetermined spacing $\Delta\lambda_{c0}$ is preferably set to be approximately equal to those in the other stations.

Figs. 8A and 8B are drawings to illustrate the operation of the control circuit 101 in the present embodiment. Fig. 8A is a drawing to show a time change of numerical data N output from the CPU 201 to the D/A converter 202-2. In other words, it shows a time change of the passing wavelength of the wavelength-variable filter 105. In the drawing, A1 to A5 represent points where the transmission wavelength of the self station is detected and B1 to B5 points where the transmission wavelength of the other station is detected. Fig. 8B is a drawing to show a time change of numerical data M output from the A/D converter 203 to the CPU 201. The time scale of the abscissa corresponds to that of Fig. 8A.

Now explained is the operation upon transmission of the present embodiment having the above arrangement.

In the present embodiment, the transmitter 402 is connected through the optical dividing / power multiplexing element 401 to the transmission line. The setup of the wavelength control system enclosed in the transmitter 402 is shown in Fig. 3. In order to avoid interference and to effectively use the wavelengths, the control circuit 101 controls the wavelength (i.e., the transmission wavelength) of the output light from the wavelength-variable light source 103 and the passing wavelength of the wavelength-variable filter 105 in the following manner.

The control circuit 101 first sets the transmission wavelength λ_k and further sets the passing wavelength λ_{f1} of the wavelength-variable filter 105 on the shorter wavelength side than λ_k . Then it sweeps the passing wavelength to the longer wavelength side, so that it then detects the transmission wavelength λ_k of the self station and the transmission wavelength λ_{k-1} of the other station adjacent thereto on the longer wavelength side. This operation yields the wavelength spacing $\Delta\lambda_c$ between the two wavelengths. Further, the control circuit 101 controls the transmission wavelength of the self station so that $\Delta\lambda_c$ may be equal to the predetermined value $\Delta\lambda_{c0}$. After that, the control circuit repeats the operation of setting the sweep start wavelength, sweeping the passing wavelength to obtain $\Delta\lambda_c$, and controlling the transmission wavelength λ_k of the self station. As a result, the wavelength spacing $\Delta\lambda_c$ converges to $\Delta\lambda_{c0}$. In the specification, a state in which the wavelength spacing is converged at the predetermined spacing $\Delta\lambda_{c0}$ will be called as a steady state, and a state before reaching it as a non-steady state. It is, however, noted that the predetermined spacing cannot be precisely one value even in the steady state, but it has the permissible width.

Figs. 7A to 7D show states of the control. The control circuit 101 starts the sweep from the wavelength λ_{f1} shifted by $\Delta\lambda_a$ from λ_k on the shorter wavelength side and monitors the intensity of transmitted light as sweeping the passing wavelength of the filter to the longer wavelength side. A first peak is obtained at the transmission wavelength λ_k of the self station, and a second peak at the transmission wavelength λ_{k-1} of the other station. The control circuit 101 finishes the sweep of the passing wavelength at the wavelength λ_{f2} shifted by $\Delta\lambda_b$ from λ_{k-1} on the longer wavelength side. This sweep from λ_{f1} to λ_{f2} is one sweep step. Here, $\Delta\lambda_a$ is a margin for surely detecting the transmission wavelength of the self station and $\Delta\lambda_b$ similarly a margin for surely detecting the transmission wavelength of the other station.

The control circuit 101 controls the transmission wavelength λ_k of the self station so that $\Delta\lambda_c$ may become equal to the predetermined value $\Delta\lambda_{c0}$, and again sets the sweep start wavelength λ_{f1} in accordance therewith. Namely, if $\Delta\lambda_c > \Delta\lambda_{c0}$ (Fig. 7A) the control circuit increases λ_k and λ_{f1} by $\Delta\lambda_d$ (Fig. 7B); if $\Delta\lambda_c = \Delta\lambda_{c0}$ (Fig. 7C) the control circuit maintains the values of λ_k and λ_{f1} ; if $\Delta\lambda_c < \Delta\lambda_{c0}$ (Fig. 7D) the control circuit decreases λ_k and λ_{f1} by $\Delta\lambda_d'$. The control circuit 101 then starts next sweep from λ_{f1} thus set, and repeats the control as described above, thereby effecting the control to bring the non-steady state to the steady state or to maintain the steady state.

If the values of $\Delta\lambda_d$ and $\Delta\lambda_d'$ are set to $|\Delta\lambda_c - \Delta\lambda_{c0}|$, $\Delta\lambda_c$ can approach $\Delta\lambda_{c0}$ most quickly. However, if the above setting of $\Delta\lambda_d$ and $\Delta\lambda_d'$ is not suitable from circumstances including the accuracy of passing wavelength or response speed of the wavelength-variable filter, a suitable arrangement is such that a proper fixed value $\Delta\lambda_{d0}$ is determined and the transmission wavelength λ_k of the self station is changed by

$$\Delta\lambda_{d0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| \geq \Delta\lambda_{d0}, \text{ or } \Delta\lambda_c - \Delta\lambda_{c0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| < \Delta\lambda_{d0}.$$

When the self station starts transmission, the transmission wavelength λ_k is set so as not to cause interference with transmission wavelengths under communication, which have already been sent to the transmission line. This can be

realized for example by setting a transmission start region in a region on the shortest wavelength side in the wavelength range handled by itself.

Namely, transmission is started in the transmission start region, and if the steady state is achieved in the transmission start region the transmission is interrupted. The transmission start region may be properly set to a region including approximately the predetermined spacing as described above or including an error of the wavelength-variable filter if it cannot be ignored.

If the entire wavelength range is arranged as a transmissible region without setting a specific transmission start region, it is first checked whether transmission light of other stations is present or absent near the transmission start wavelength prior to transmission start, and then transmission is started only when a necessary wavelength region is secured. Specifically, supposing that all transmission start wavelengths of respective stations are over a wavelength λ_{limit} and that errors of the wavelength-variable filters in the transmitters of respective stations (differences between actual wavelengths and transmission wavelengths expected for the transmitters) are below $\Delta\lambda_{\text{error}}$, the wavelength-variable filter is swept upon transmission start at least from the shorter wavelength side than λ_{limit} to $\lambda_{\text{limit}} + \Delta\lambda_{\text{error}} + \Delta\lambda_{\text{c0}}$, and, without detection of a transmission wavelength of any other station, transmission is started as judging that the wavelength range not to cause interference upon transmission start can be secured.

There is another method not including such special means for avoiding interference upon transmission start. In this case, interference occurs if a transmission wavelength of one other station exists near the transmission start wavelength upon transmission start. Even with interference, because the transmission wavelength of the station which started transmission later is controlled so as to keep the predetermined spacing relative to the adjacent transmission wavelength in accordance with the above-described control, the transmission of the station having started the transmission later is quickly interrupted. In this case, if transmission data in the interfered communication is data which permits abnormal receiving of partial data (for example, data permitting partial lack like dynamic picture data) the former transmission is continued without interruption; if the data does not permit abnormal receiving of partial data, a receiving station requests retransmission.

A transmission start method may be selected depending upon the wavelength region handled, the predetermined spacing $\Delta\lambda_{\text{c0}}$, data transmitted, etc. from the above methods upon transmission start.

It is also conceivable that sweep results in reaching the longest wavelength side of the wavelength range handled by the self station without detecting any transmission signal of another station. For example, such a case may occur when the self station starts communication while neither station is in communication in the present communication system. In this case, the control circuit 101 changes the transmission wavelength of the self station to the longest wavelength side and stops there. Specifically, it holds an output from the drive circuit 102-1 for driving the wavelength-variable light source 103 at the output corresponding to the longest wavelength side.

Next explained in detail using Figs. 8A and 8B is the operation of the control circuit 101 in the present embodiment, performing the wavelength control as discussed above.

The control circuit 101 sets the transmission wavelength λ_k of the self station by outputting a suitable voltage to the drive circuit 102-1. The voltage corresponds to the numerical data output from the CPU 201 to the D/A converter 202-1. Further, the control circuit 101 always sweeps the passing wavelength of the wavelength-variable filter 105 in order to obtain the wavelength spacing $\Delta\lambda_{\text{c}}$ between the transmission wavelength λ_k of the self station and the transmission wavelength λ_{k-1} of the other station. For that purpose, the CPU 201 sends the numerical data N to the D/A converter 202-2 and increases a value thereof by Δn every short period Δt . Here, the a numerical value sent to the D/A converter 202-2 corresponds to the passing wavelength of the wavelength-variable filter 105, and Δn to the smallest change of the passing wavelength of the wavelength-variable filter 105. At the same time, the CPU 201 monitors the numerical value M output from the A/D converter 203. The numerical value M corresponds to the intensity of the light transmitted by the wavelength-variable filter 105.

As the CPU 201 increases the numerical data N sent to the D/A converter 202-2 (Fig. 8A), the numerical value M output from the A/D converter 203 comes to have a peak at a transmission wavelength of each station (Fig. 8B). The first peak (numerical value NA1) at point A1 corresponds to the transmission wavelength λ_k of the self station, and the second peak (numerical value NB1) at point B1 to the transmission wavelength λ_{k-1} of the other station. Then the CPU 201 calculates $\Delta N = NB1 - NA1$, which is a quantity corresponding to the wavelength spacing $\Delta\lambda_{\text{c}}$, and compares it with a preliminarily determined numerical value ΔN_0 corresponding to $\Delta\lambda_{\text{c0}}$, thereby comparing $\Delta\lambda_{\text{c}}$ with $\Delta\lambda_{\text{c0}}$. The CPU 201 again sets the transmission wavelength λ_k of the self station and the sweep start wavelength λ_{f1} , based on a result of the comparison.

If $\Delta N > \Delta N_0$, the CPU 201 shifts the transmission wavelength λ_k of the self station and the sweep start wavelength λ_{f1} by $\Delta\lambda_d$ to the longer wavelength side. Namely, the CPU increases the numerical data sent to the D/A converters 202-1, 202-2 by the value corresponding to $\Delta\lambda_d = |\Delta\lambda_{\text{c}} - \Delta\lambda_{\text{c0}}|$ (from A1 to A2). After that, sweep of, the passing wavelength is started.

If $\Delta N = \Delta N_0$, the CPU 201 again performs sweep as keeping the same setting as upon the previous sweep (from A3 to A4).

If $\Delta N < \Delta N_0$, the CPU 201 shifts the transmission wavelength λ_k of the self station and the sweep start wavelength λ_{f1} by $\Delta\lambda d' = |\Delta\lambda c' - \Delta\lambda c_0|$ to the shorter wavelength side. Namely, the CPU decreases the numerical data sent to the D/A converters 202-1, 202-2 by the value corresponding to $\Delta\lambda d'$ (from A4 to A5). After that, sweep of the passing wavelength is started.

The wavelength control as described forms an array of transmission wavelengths from the respective stations with the head on the longer wavelength side on the wavelength axis in the transmission line. After a certain station ends transmission, a gap appears in the array of transmission wavelengths thus arranged. On that occasion, an array of transmission wavelengths located on the shorter wavelength side than the gap move to the longer wavelength side so as to bridge the gap, whereby the wavelength region can be effectively used.

For example, let us suppose that m terminal stations 303-1 to 303- m in Fig. 9 are transmitting signals, using the respective wavelengths of λ_1 to λ_m . Now let us consider a case that the terminal station 303- k transmitting its signal with the wavelength λ_k stops transmission. Since the transmission wavelength λ_k is now absent in the transmission line, the terminal station 303- $k + 1$ comes not to detect any transmission signal from the other stations. Accordingly, the control circuit 101 in the terminal station 303- $k + 1$ changes the transmission wavelength $\lambda_k + 1$ of the self station to the longer wavelength side before it detects a transmission signal of another station. On the other hand, the terminal stations transmission their signals using the respective wavelengths on the shorter wavelength side than the terminal station 303- $k + 1$ control their own transmission wavelengths so that each station may keep constant a wavelength difference between the transmission wavelength of the self station and the transmission wavelength of the other station one wavelength adjacent thereto on the longer wavelength side. Therefore, the transmission wavelengths of those terminal stations move to the longer wavelength side as following up the transmission wavelength of the terminal station 303- $k + 1$, thereby finally filling the gap.

The operation upon receiving is next explained.

The light coming from the transmission line advances through the optical dividing / power multiplexing element 401 to reach the receiver 403. The receiver receives only a light signal of the transmission wavelength λ_k of a terminal station intended to receive and then converts it into an electric signal to output it to the terminal equipment.

The receiver 403 always checks whether there exists a signal newly sent to the transmission line or not. This will be called as a receiving standby state. Any terminal station not transmitting or receiving a signal is in the receiving standby state. A terminal station in the receiving standby state sets the receiving wavelength thereof on the longer wavelength side than the transmission start wavelengths of the respective stations to wait for a transmission signal from one other station. If there is a signal newly sent, the terminal station in the standby state determines whether it is a signal directed to the self station. If the signal is directed to the self station, it receives the signal; if not, the terminal station continues checking presence or absence of the signal.

While a certain receiver 403 is receiving, for example, the transmission wavelength λ_k from the terminal station 303-1 and when the terminal station 303-1 moves the transmission wavelength λ_k in order to avoid interference or in order to keep the wavelength spacing at the predetermined spacing, the receiver 403 also moves the receiving wavelength in accordance therewith. This can be realized for example by applying the control method for making the passing wavelength of the wavelength-variable filter coincident with the transmission wavelength in the transmitter, as described previously, to the wavelength-variable filter in the receiver.

Applying the optical receiving device 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, a transmitting station can continue transmission as avoiding interference and a receiving station can continue receiving without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, it is not necessary to achieve precise stability of the transmission wavelength of each station.

(Embodiment 2)

The second embodiment of the present invention is next explained with reference to the drawings.

The present embodiment has the same configuration as the first embodiment, but is different in the method for controlling the wavelength-variable light source and the wavelength-variable filter in the transmitter. Specifically, return sweep is also utilized as one sweep step upon obtaining the wavelength spacing $\Delta\lambda c$ between the transmission wavelength of the self station and the transmission wavelength of the other station.

The schematic drawing of a system for achieving the wavelength-multiplexing optical communication method of the present embodiment is shown in Fig. 5, the schematic drawing of the optical transmitter-receiver portion in each station in Fig. 6, the setup of the transmitter in Fig. 3, and the setup of the control circuit in the transmitter in Fig. 4. Since the elements in the respective portions are the same as those in the first embodiment, description thereof is omitted herein.

Figs. 10A, 10B are drawings to illustrate the operation of the control circuit 101 in the present embodiment. Fig. 10A is a drawing to show a time change of the numerical data N output from the CPU 201 to the D/A converter 202-2. In other words, it shows a time change of the wavelength transmitted by the wavelength-variable filter 105. In the drawings,

A1 to A10 are points where the transmission wavelength of the self station is detected, and B1 to B10 points where the transmission wavelength of the other station is detected. Further, Fig. 8B is a drawing to show a time change of the numerical data M output from the A/D converter 203 to the CPU 201. The time scale of the abscissa corresponds to that of Fig. 10A.

The operation of the present embodiment having the above arrangement is next explained focusing on the difference from the first embodiment.

In order to avoid interference and to effectively use the wavelengths upon transmission, the control circuit 101 controls the wavelength (or the transmission wavelength) of the output light and the passing wavelength of the wavelength-variable filter 105.

The control circuit 101 first sets the transmission wavelength λ_k of the self station and further sets the passing wavelength λ_{f1} of the wavelength-variable filter 105 on the shorter wavelength side than λ_k . Next the control circuit sweeps the passing wavelength to the longer wavelength side to detect the transmission wavelength of the self station λ_k and the transmission wavelength λ_{k-1} of the other station adjacent thereto on the longer wavelength side. This yields the wavelength spacing $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ between the two wavelengths. Then the control circuit 101 controls the transmission wavelength of the self station λ_k so that $\Delta\lambda_c$ may become equal to the predetermined value $\Delta\lambda_{c0}$. Namely, if $\Delta\lambda_c > \Delta\lambda_{c0}$ the control circuit increases λ_k by $\Delta\lambda_d$; if $\Delta\lambda_c = \Delta\lambda_{c0}$ the control circuit maintains the value of λ_k ; if $\Delta\lambda_c < \Delta\lambda_{c0}$ the control circuit decreases λ_k by $\Delta\lambda_d$. Further, λ_{f1} is also updated in correspondence thereto.

Then the passing wavelength of the wavelength-variable filter 105 is swept back to the shorter wavelength side from λ_{f2} to λ_{f1} thus updated, thereby detecting λ_{k-1} , λ_k in order and then obtaining the wavelength spacing $\Delta\lambda_c$. The control circuit 101 again controls the transmission wavelength of the self station so that $\Delta\lambda_c$ may become equal to $\Delta\lambda_{c0}$. After that, the control circuit repeats the operation of obtaining the wavelength spacing $\Delta\lambda_c$ as alternately changing the sweep direction of the passing wavelength every sweep step and controlling the transmission wavelength λ_k of the self station.

As a result, the wavelength spacing $\Delta\lambda_c$ comes to converge to $\Delta\lambda_{c0}$.

If the values of $\Delta\lambda_d$ and $\Delta\lambda_d'$ are set to $|\Delta\lambda_c - \Delta\lambda_{c0}|$, $\Delta\lambda_c$ can approach $\Delta\lambda_{c0}$ most quickly. If it is not suitable, a possible arrangement is such that a suitable fixed value $\Delta\lambda_{d0}$ is selected and that the transmission wavelength of the self station λ_k is changed by

$$\Delta\lambda_{d0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| \geq \Delta\lambda_{d0}, \text{ or } \Delta\lambda_c - \Delta\lambda_{c0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| < \Delta\lambda_{d0}.$$

These are the same as in the first embodiment.

Since the present embodiment also utilizes the return sweep upon obtaining the wavelength spacing $\Delta\lambda_c$, the wavelength spacing $\Delta\lambda_c$ can come to converge to $\Delta\lambda_{c0}$ faster than in the first embodiment.

Next explained in detail using Figs. 10A and 10B is the operation of the control circuit 101 in the present embodiment, performing the wavelength control as described above.

Similarly as in the first embodiment, the numerical data output from the CPU 201 to the D/A converter 202-1 corresponds to the transmission wavelength λ_k of the self station. Similarly, the numerical data N sent from the CPU 201 to the D/A converter 202-2 corresponds to the passing wavelength of the wavelength-variable filter 105, and sweep of the passing wavelength is effected by increasing or decreasing the value of the numerical data by Δn every very short period Δt . Further, the numerical value M output from the A/D converter 203 corresponds to the intensity of the light transmitted by the wavelength-variable filter 105.

As the CPU 201 increases the numerical data N sent to the D/A converter 202-2 (Fig. 10A), the numerical value M output from the A/D converter 203 comes to have a peak at a transmission wavelength of each station (Fig. 10B). For example, suppose that a peak corresponding to the transmission wavelength λ_k of the self station appears at the numerical value NA1 and a peak corresponding to the transmission wavelength λ_{k-1} of the other station at the numerical value NB1. The CPU 201 calculates $\Delta N = \Delta NB1 - \Delta NA1$, which is a quantity corresponding to the wavelength spacing $\Delta\lambda_c$, and compares it with ΔN_0 , which is a quantity corresponding to $\Delta\lambda_{c0}$.

If $\Delta N > \Delta N_0$, the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side. Namely, the CPU increases the numerical data sent to the D/A converter 202-1 by a value corresponding to $\Delta\lambda_d$ (from A1 to A2 and from A2 to A3), and continues sweeping.

If $\Delta N = \Delta N_0$, the CPU 201 maintains the same setting as upon the previous sweep (from A5 to A6, from A6 to A7, from A8 to A9, and from A9 to A10), and again executes sweeping.

If $\Delta N < \Delta N_0$, the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d'$ to the shorter wavelength side. Namely, the CPU decreases the numerical data sent to the D/A converter 202-1 by a value corresponding to $\Delta\lambda_d'$ (from A7 to A8), and continues sweeping.

The wavelength control as described above forms an array of transmission wavelengths from the respective stations with the head on the longer wavelength side in the order of starts of communication on the wavelength axis in the transmission line, similarly as in the first embodiment. Further, with end of transmission of a certain terminal station, a gap appearing in the array of transmission wavelengths is also automatically bridged in the same manner as in the first embodiment. The setting method of the transmission wavelength λ_k upon transmission start, the control method when

the transmission wavelength of the self station reaches the longest wavelength side of the wavelength range handled by itself, and the operation upon receiving are based on those in the first embodiment.

Applying the optical receiving device 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, the transmitting station can continue transmitting signals as avoiding interference, and the receiving station can continue receiving signals without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, precise stabilization is not necessary for the transmission wavelength of each station. Since the present embodiment also utilizes the return sweep as one sweep step, the wavelength spacing can be converged faster without quickly changing the passing wavelength of the wavelength-variable filter, as compared with Embodiment 1, and the margin for surely detecting the transmission wavelength of the self station can be set to 0 or to be very small.

(Embodiment 3)

The third embodiment of the present invention is next explained with reference to the drawings.

The present embodiment has the same configuration as the first embodiment, but is different from the first and second embodiments in the control method of the wavelength-variable light source and the wavelength-variable filter in the transmitter. Embodiments 1, 2 were arranged to detect the two wavelengths, i.e. the transmission wavelength of the self station and an adjacent transmission wavelength, in one sweep step even in the non-steady state, whereas Embodiments 3 and 4 to follow are arranged to detect only one wavelength in one sweep step before approach of the steady state.

Specifically, the present embodiment is so arranged that, in order to obtain the wavelength spacing $\Delta\lambda_c$ between the transmission wavelength of the self station and the transmission wavelength of the other station, the passing wavelength of the wavelength-variable filter is repeatedly swept in a longer wavelength region in the proximity wavelength region to the transmission wavelength of the self station.

The schematic drawing of a system for achieving the wavelength-multiplexing optical communication system of the present embodiment is shown in Fig. 5, the schematic drawing of the optical transmitter-receiver portion of each station in Fig. 6, the setup of the transmitter in Fig. 3, and the setup of the control circuit in the transmitter in Fig. 4. Since the elements in the respective portions are the same as those in the first embodiment, the description thereof is omitted herein.

Figs. 11A to 11D are drawings to show relations on the wavelength axis between the communicating wavelengths and the passing wavelength of the wavelength filter where a plurality of terminal stations are in communication by the present method. In the drawings, λ_1 to λ_{k-1} represent the transmission wavelengths of other stations, λ_k the transmission wavelength of the self station, λ_{f1} the sweep start wavelength of the wavelength-variable filter 105 of the self station, λ_{f2} the sweep return wavelength thereof, and $\Delta\lambda_a$ a margin for surely detecting the transmission wavelength of the self station. Further, $\Delta\lambda_e$ is the width of sweep for surely detecting the transmission wavelength of the other station without causing interference with the transmission wavelength of the self station. In the drawings, $\Delta\lambda_c$ represents the wavelength spacing between λ_k and λ_{k-1} , and $\Delta\lambda_d$, $\Delta\lambda_d'$ moving amounts of λ_k , λ_{f1} and λ_{f2} . Figs. 11A and 11B show cases where $\Delta\lambda_c$ is greater than the predetermined value, Fig. 11C a case where $\Delta\lambda_c$ is equal to the predetermined value, and Fig. 11D a case where $\Delta\lambda_c$ is smaller than the predetermined value.

Figs. 12A and 12B are drawings to illustrate the operation of the control circuit 101 in the present embodiment. Fig. 12A is a drawing to show a time change of the numerical data N output from the CPU 201 to the D/A converter 202-2. In other words, it shows a time change of the passing wavelength of the wavelength-variable filter 105. In the drawing, A1 to A12 represent points where the transmission wavelength of the self station is detected, and B5 to B12 points where the transmission wavelength of the other station is detected. Further, Fig. 12B is a drawing to show a time change of the numerical data M output from the A/D converter 203. The time scale of the abscissa corresponds to that of Fig. 12A.

The operation of the present embodiment having the above arrangement is next explained focusing on the difference from the first and second embodiments.

Upon sending signals, in order to avoid interference and to effectively use the wavelengths, the control circuit 101 repeats the following operation. The control circuit first sets the transmission wavelength λ_k and then sets the passing wavelength of the wavelength-variable filter 105 on the shorter wavelength side than λ_k . The control circuit 101 sweeps the passing wavelength to the longer wavelength side as checking presence or absence of a transmission wavelength. Sweep is continued after detecting the transmission wavelength λ_k of the self station and turns back to the shorter wavelength side at a suitable wavelength. Then the control circuit continues sweeping to the shorter wavelength side as checking presence or absence of a transmission wavelength. Once it detects the transmission wavelength of the self station λ_k , sweep again turns back to the longer wavelength side.

This is carried out for the purpose of checking presence or absence of the transmission wavelength of the other station and a change thereof in the proximity wavelength region on the longer wavelength side than the transmission wavelength λ_k of the self station. The control circuit 101 controls the transmission wavelength of the self station λ_k in

such a manner that if it does not detect the transmission wavelength of the other station λ_{k-1} it changes the transmission wavelength of the self station λ_k to the longer wavelength side; if it detects λ_{k-1} it adjusts the wavelength spacing $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ between the two wavelengths so as to become equal to the predetermined value $\Delta\lambda_{c0}$.

Figs. 11A to 11D show the details of the control. The control circuit 101 starts sweeping from the wavelength λ_{f1} shifted by $\Delta\lambda_a$ on the shorter wavelength side than λ_k and monitors the intensity of transmitted light as sweeping the passing wavelength of the filter to the longer wavelength side. A peak appears at the transmission wavelength of the self station λ_k , and the control circuit 101 continues sweeping up to the wavelength λ_{f2} shifted by $\Delta\lambda_e$ on the longer wavelength side from λ_k . Then the control circuit reverses the direction of sweep to the shorter wavelength side, and, detecting another peak of the transmission wavelength of the self station λ_k , it continues sweeping up to the wavelength λ_{f1}' shifted by $\Delta\lambda_a$ on the shorter wavelength side from λ_k .

If the control circuit does not detect the transmission wavelength of the other station λ_{k-1} (Fig. 11A) or if it detects λ_{k-1} but a difference from the transmission wavelength of the self station λ_k is greater than $\Delta\lambda_{c0}$, the control circuit 101 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side. As a result (Fig. 11B), the transmission wavelength of the self station λ_k , the sweep start wavelength λ_{f1} , and the sweep turning wavelength λ_{f2} each increase by $\Delta\lambda_d$.

If the control circuit detects the transmission wavelength of the other station λ_{k-1} and if the difference from the transmission wavelength of the self station λ_k is equal to the predetermined value $\Delta\lambda_{c0}$ (Fig. 11C), the control circuit 101 maintains the value of λ_k .

If the control circuit detects the transmission wavelength of the other station λ_{k-1} and if the difference $\Delta\lambda_c$ between the transmission wavelength of the self station λ_k and the transmission wavelength of the other station λ_{k-1} is smaller than the predetermined value $\Delta\lambda_{c0}$, the control circuit 101 shifts the transmission wavelength of the self station by $\Delta\lambda_d'$ to the shorter wavelength side.

Then the control circuit sweeps back the passing wavelength of the wavelength-variable filter 105 to the shorter wavelength side to detect λ_{k-1} , λ_k in order, thereby obtaining the wavelength spacing $\Delta\lambda_c$. Then the control circuit 101 again controls the transmission wavelength of the self station so that $\Delta\lambda_c$ may become equal to $\Delta\lambda_{c0}$.

After that, the control circuit repeats such operation as to obtain the wavelength spacing $\Delta\lambda_c$ as alternately changing the sweep direction of the passing wavelength and then to control the transmission wavelength λ_k of the self station. As a result, the wavelength spacing $\Delta\lambda_c$ comes to converge to $\Delta\lambda_{c0}$.

The spacing $\Delta\lambda_c$ can approach $\Delta\lambda_{c0}$ most quickly by setting the value of $\Delta\lambda_d$ to $\Delta\lambda_e$ if the control circuit 101 does not detect the transmission wavelength of the other station λ_{k-1} or to $|\Delta\lambda_c - \Delta\lambda_{c0}|$ if the control circuit 101 detects the transmission wavelength of the other station λ_{k-1} and setting the value of $\Delta\lambda_d'$ to $|\Delta\lambda_c - \Delta\lambda_{c0}|$. If it is not suitable in respect of the response speed, a possible arrangement may be determined in such a manner that a suitable fixed value $\Delta\lambda_{d0}$ to which the system can properly respond is determined, the fixed value is compared with $|\Delta\lambda_c - \Delta\lambda_{c0}|$ (or with $\Delta\lambda_b$ if λ_{k-1} is not detected for $\Delta\lambda_d$), and the smaller one is used.

Next explained in detail using Figs. 12A and 12B is the operation of the control circuit 101 in the present embodiment, performing the wavelength control as described above.

Similar to the first and second embodiments, the numerical data output from the CPU 201 to the D/A converter 202-1 corresponds to the transmission wavelength λ_k of the self station. Similarly, the numerical data N sent from the CPU 201 to the D/A converter 202-2 corresponds to the passing wavelength of the wavelength-variable filter 105, and sweep of the passing wavelength is carried out by increasing or decreasing the value by Δn every very short period Δt . Also, the numerical value M output from the A/D converter 203 corresponds to the intensity of the light transmitted by the wavelength-variable filter 105.

As the CPU 201 increases or decreases the numerical data N sent to the D/A converter 202-2 (Fig. 12A), the numerical value M output from the A/D converter 203 comes to have peaks corresponding to the transmission wavelengths of the respective stations (Fig. 12B). The CPU 201 sweeps regions near the peaks (point A1 to point A12) corresponding to the transmission wavelength λ_k of the self station within a certain sweep width (corresponding to $\Delta\lambda_a + \Delta\lambda_e$ in Figs. 11A to 11D) in order to find the peaks (point B5 to point B12) corresponding to the transmission wavelength λ_{k-1} of the other station.

Failing to find a peak corresponding to λ_{k-1} during one sweep step, that is, during sweep of from λ_{f1} to λ_{f2} or from λ_{f2} to λ_{f1} , the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side. Namely, the CPU increases the numerical data N sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d$ (from A1 to A2, from A2 to A3, and from A3 to A4), and thus continues sweeping.

Once it finds out a peak (point B5 to point B12) corresponding to λ_{k-1} , the CPU 201 executes the following processing. For example, suppose that a peak corresponding to λ_k appears when the numerical value sent to the D/A converter 202-2 is NA and that a peak corresponding to λ_{k-1} appears when the numerical value is NB. Then the CPU 201 calculates $\Delta N = \Delta NB - \Delta NA$, which is a quantity corresponding to the wavelength spacing $\Delta\lambda_c$, and compares it with ΔN_0 , which is a quantity corresponding to the predetermined value $\Delta\lambda_{c0}$.

If $\Delta N > \Delta N_0$, the CPU 201 shifts λ_k by $\Delta\lambda_d$ to the longer wavelength side. Namely, the CPU increases the numerical data sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d$ (from A5 to A6), and then continues sweeping.

If $\Delta N = \Delta N_0$, the CPU 201 maintains the same setting as upon previous sweep (from A6 to A7, from A7 to A8, from A8 to A9, from A10 to A11, and from A11 to A12), and again performs sweeping.

If $\Delta N < \Delta N_0$, the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d'$ to the shorter wavelength side. Namely, the CPU decreases the numerical data sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d'$ (from A9 to A10), and then continues sweeping.

The wavelength control as described above forms an array of the transmission wavelengths from the respective stations with the head on the longer wavelength side in order of communication start on the wavelength axis in the transmission line, similarly as in the first embodiment. Further, with transmission end of a certain terminal station, a gap appearing in the array of transmission wavelengths is automatically bridged, which is also the same. In addition, the setting method of the transmission wavelength λ_k upon transmission start, the control method when the transmission wavelength of the self station reaches the longest wavelength side of the wavelength range handled by itself, and the operation upon receiving signals are also based on those in the first embodiment.

Applying the optical receiving device 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, a transmitting station can continue transmission as avoiding interference and a receiving station can continue receiving without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, it is not necessary to achieve precise stability of the transmission wavelength of each station.

(Embodiment 4)

The fourth embodiment of the present invention is next explained with reference to the drawings.

The present embodiment is arranged to detect only one wavelength in one sweep step before approach of the steady state, similarly as in Embodiment 3. The present embodiment is different from Embodiment 3 in that, in order to obtain the wavelength spacing $\Delta\lambda_c$ between the transmission wavelength of the self station and the transmission wavelength of the other station, the passing wavelength of the wavelength-variable filter is repeatedly swept in a shorter-wavelength-side region in the proximity wavelength region to the transmission wavelength of the other station adjacent to the transmission wavelength of the self station on the longer wavelength side.

The schematic drawing of a system for achieving the wavelength-multiplexing optical communication method of the present embodiment is shown in Fig. 5, the schematic drawing of the optical transmitter-receiver portion of each station in Fig. 6, the setup of the transmitter in Fig. 3, and the setup of the control circuit in the transmitter in Fig. 4. Since the elements in the respective portions are the same as those in the first embodiment, the description thereof is omitted herein.

Figs. 13A to 13D are drawings to show relations on the wavelength axis between the communicating wavelengths and the passing wavelength of the wavelength-variable filter where there are a plurality of terminal stations communicating by the present method. In the drawings, λ_1 to λ_{k-1} represent transmission wavelengths of other stations, λ_k the transmission wavelength of the self station, λ_{f1} the sweep start wavelength of the wavelength-variable filter 105 of the self station, λ_{f2} the sweep turning wavelength thereof, and $\Delta\lambda_a$ a margin for surely detecting the transmission wavelength of the self station λ_k before the transmission wavelength λ_k of the self station comes to interfere with the transmission wavelength λ_{k-1} of the other station. Further, $\Delta\lambda_b$ is a margin for surely detecting the transmission wavelength of the other station λ_{k-1} . In addition, $\Delta\lambda_c$ is the wavelength spacing between λ_k and λ_{k-1} . In the drawings, $\Delta\lambda_d$, $\Delta\lambda_d'$ represent moving amounts of λ_k , λ_{f1} , and λ_{f2} . Figs. 13A and 13B show cases where $\Delta\lambda_c$ is greater than the predetermined value, Fig. 13C a case where $\Delta\lambda_c$ is equal to the predetermined value, and Fig. 13D a case where $\Delta\lambda_c$ is smaller than the predetermined value.

Figs. 14A and 14B are drawings to illustrate the operation of the control circuit 101 in the present embodiment. Fig. 14A is a drawing to show a time change of the numerical data N output from the CPU 201 to the D/A converter 202-2. In other words, Fig. 14A shows a time change of the passing wavelength of the wavelength-variable filter 105. In the drawing, A1, A3 to A10 represent points where the transmission wavelength of the self station is detected, and B1 to B10 points where the transmission wavelength of the other station is detected. Fig. 14B is a drawing to show a time change of the numerical data M output from the A/D converter 203. The time scale of the abscissa corresponds to that of Fig. 14A.

The operation of the present embodiment having the above arrangement is next explained particularly focusing on the difference from the first, second, and third embodiments.

Upon transmission, in order to avoid interference and to effectively use the wavelengths, the control circuit 101 repeats the following operation.

The control circuit first sets the transmission wavelength λ_k and then sets the passing wavelength of the wavelength-variable filter 105 on the shorter wavelength side than λ_k . The control circuit 101 then sweeps the passing wavelength to the longer wavelength side as checking presence or absence of a transmission wavelength, thereby detecting the transmission wavelength of the self station λ_k and the transmission wavelength λ_{k-1} of the other station adjacent thereto

on the longer wavelength side. The control circuit 101 calculates the wavelength spacing $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ between the two wavelengths, and controls the transmission wavelength λ_k of the self station so that $\Delta\lambda_c$ may become equal to the predetermined value $\Delta\lambda_{c0}$. Namely, it increases λ_k by $\Delta\lambda_d$ if $\Delta\lambda_c > \Delta\lambda_{c0}$; it maintains the value of λ_k if $\Delta\lambda_c = \Delta\lambda_{c0}$; it decreases λ_k by $\Delta\lambda_d'$ if $\Delta\lambda_c < \Delta\lambda_{c0}$.

Then the control circuit 101 turns the passing wavelength of the wavelength-variable filter 105 back to the shorter wavelength side, and then continues sweeping as checking presence or absence of a transmission wavelength. After detecting the transmission wavelength of the other station λ_{k-1} , the control circuit continues sweeping and then turns sweep back to the longer wavelength side at an appropriate wavelength. Then it continues sweeping as checking presence or absence of a transmission wavelength, and, once detecting the transmission wavelength λ_{k-1} of the other station, it again turns sweep back to the longer wavelength side.

This is carried out for the purpose of checking presence or absence of the transmission wavelength of the self station and a change thereof in the proximity wavelength region on the shorter wavelength side of the transmission wavelength of the other station λ_{k-1} . If the control circuit 101 does not detect the transmission wavelength of the self station λ_k it changes the transmission wavelength of the self station λ_k to the longer wavelength side; if it detects λ_k it controls the transmission wavelength of the self station λ_k so that the wavelength spacing $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ between the two wavelengths may become equal to the predetermined value $\Delta\lambda_{c0}$.

Figs. 13A to 13D show the details of the control. The control circuit 101 starts sweeping from the wavelength λ_{f1} shifted by $\Delta\lambda_a$ to the shorter wavelength side from λ_k , and monitors the intensity of the transmitted light as sweeping the passing wavelength of the filter to the longer wavelength side. A peak appears at a transmission wavelength of each station. The control circuit 101 first detects the transmission wavelength λ_k of the self station and the transmission wavelength λ_{k-1} of the other station adjacent thereto on the longer wavelength side. After detecting λ_{k-1} , the control circuit 101 continues sweeping from λ_{k-1} up to the wavelength λ_{f2} shifted by $\Delta\lambda_b$ on the longer wavelength side.

The control circuit 101 calculates the wavelength spacing $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ between the transmission wavelength of the other station λ_{k-1} and the transmission wavelength of the self station λ_k , and compares it with the predetermined value $\Delta\lambda_{c0}$. If $\Delta\lambda_c > \Delta\lambda_{c0}$, the control circuit changes the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side (Fig. 13A); if $\Delta\lambda_c = \Delta\lambda_{c0}$ it maintains the value of λ_k ; if $\Delta\lambda_c < \Delta\lambda_{c0}$ it changes λ_k by $\Delta\lambda_d'$ to the shorter wavelength side.

Then the control circuit 101 reverses the direction of sweep to the shorter wavelength side, and, once detecting a peak of the transmission wavelength of the other station λ_{k-1} , it continues sweeping from λ_{k-1} to the wavelength λ_{f1}' shifted by $\Delta\lambda_a + \Delta\lambda_{c0}$ on the shorter wavelength side.

If the control circuit does not detect the transmission wavelength of the self station λ_k' (Fig. 13B) or if it detects λ_k' but a difference from the transmission wavelength of the other station λ_{k-1} is greater than the predetermined value $\Delta\lambda_{c0}$, the control circuit 101 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side.

If the control circuit detects the transmission wavelength of the self station λ_k'' and if the difference from λ_{k-1} is equal to $\Delta\lambda_{c0}$ (Fig. 13C), the control circuit 101 maintains the value of λ_k'' .

If the control circuit detects the transmission wavelength of the self station λ_k''' and if the difference $\Delta\lambda_c'$ from λ_{k-1} is smaller than $\Delta\lambda_{c0}$ (Fig. 13D), the control circuit 101 shifts the transmission wavelength of the self station by $\Delta\lambda_d'$ to the shorter wavelength side.

Then the passing wavelength of the wavelength-variable filter 105 is swept back to the longer wavelength side to detect λ_k , λ_{k-1} in order, thereby obtaining the wavelength spacing $\Delta\lambda_c$. The control circuit 101 again controls the transmission wavelength of the self station so that $\Delta\lambda_c$ may become equal to $\Delta\lambda_{c0}$.

After that, the control circuit repeats such operation as to sweep the passing wavelength in the proximity wavelength region of λ_{k-1} , obtain the wavelength spacing $\Delta\lambda_c$, and then control the transmission wavelength λ_k of the self station, as alternately changing the direction of sweep. As a result, the wavelength spacing $\Delta\lambda_c$ comes to converge to $\Delta\lambda_{c0}$.

If the values of $\Delta\lambda_d$ and $\Delta\lambda_d'$ are set to $|\Delta\lambda_c - \Delta\lambda_{c0}|$, $\Delta\lambda_c$ can approach $\Delta\lambda_{c0}$ most quickly. If it is not suitable, a possible arrangement may be constructed in such a manner that a proper fixed value $\Delta\lambda_{d0}$ is selected and the transmission wavelength of the self station λ_k is changed by

$$\Delta\lambda_{d0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| \geq \Delta\lambda_{d0}, \text{ or } \Delta\lambda_c - \Delta\lambda_{c0}, \text{ if } |\Delta\lambda_c - \Delta\lambda_{c0}| < \Delta\lambda_{d0}.$$

These are also the same as in the previous embodiments.

Next explained in detail using Figs. 14A and 14B is the operation of the control circuit 101 in the present embodiment, performing the wavelength control as described above.

Similar to the first to the third embodiments, the numerical data output from the CPU 201 to the D/A converter 202-1 corresponds to the transmission wavelength λ_k of the self station. Similarly, the numerical data N sent from the CPU 201 to the D/A converter 202-2 corresponds to the passing wavelength of the wavelength-variable filter 105, and sweep of the passing wavelength is carried out by increasing or decreasing the value by Δn every very short period Δt . The numerical value M output from the A/D converter 203 corresponds to the intensity of the light transmitted by the wavelength-variable filter 105.

As the CPU 201 increases or decreases the numerical data N sent to the D/A converter 202-2 (Fig. 14A), the numerical value M output from the A/D converter 203 comes to have a peak corresponding to the transmission wavelength of each station (Fig. 14B). The CPU 201 repeatedly sweeps the vicinity of a peak (point B1 to point B10) corresponding to the transmission wavelength of the other station λ_{k-1} with a certain sweep width (corresponding to $\Delta\lambda_a + \Delta\lambda_b + \Delta c_0$ in Figs. 13A-13B) to look for a peak corresponding to the transmission wavelength of the self station λ_k .

If the CPU fails to find a peak corresponding to λ_k , the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d$ to the longer wavelength side. Namely, the CPU increases the numerical data N sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d$, and continues sweeping.

Finding a peak (point A3 to point A10) corresponding to λ_k , the CPU 201 executes the following processing. For example, suppose that a peak corresponding to λ_k appears when the numerical value sent to the D/A converter 202-2 is NA and a peak corresponding to λ_{k-1} appears when the numerical value is NB. The CPU 201 calculates $\Delta N = \Delta NB - \Delta NA$, which is a quantity corresponding to the wavelength spacing $\Delta\lambda_c$, and compares it with ΔN_0 , which is a quantity corresponding to the predetermined value $\Delta\lambda_{c0}$.

If $\Delta N > \Delta N_0$, the CPU 201 shifts λ_k by $\Delta\lambda_d$ to the longer wavelength side. Namely, it increases the numerical data N sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d$ (from A3 to A4), and continues sweeping.

If $\Delta N = \Delta N_0$, the CPU 201 maintains the same setting as upon the previous sweep (from A5 to A6, from A8 to A9, and from A9 to A10), and again performs sweeping.

If $\Delta N < \Delta N_0$, the CPU 201 shifts the transmission wavelength of the self station λ_k by $\Delta\lambda_d'$ to the shorter wavelength side. Namely, it decreases the numerical data N sent to the D/A converter 202-1 by the value corresponding to $\Delta\lambda_d'$ (from A7 to A8), and continues sweeping.

The wavelength control as described above forms an array of the transmission wavelengths from the respective stations with the head on the longer wavelength side in order of communication starts on the wavelength axis in the transmission line, similarly as in the first embodiment. Further, with transmission end of a certain terminal station, a gap appearing in the array of transmission wavelengths is automatically bridged in the same manner as in the first embodiment. The setting method of the transmission wavelength λ_k upon transmission start, the control method when the transmission wavelength of the self station reaches the longest wavelength side of the wavelength range handled by itself, and the operation upon receiving are based on those in the first embodiment.

Applying the optical receiving device 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, a transmitting station can continue sending signals as avoiding interference, and a receiving station can continue receiving signals without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, it is not necessary to achieve precise stability of the transmission wavelength of each station.

Since the present embodiment, as well as Embodiment 3, is arranged to detect only either one of the transmission wavelength of the self station and the adjacent transmission wavelength before reaching the steady state, one sweep step is short. In the previous embodiments and the present embodiment, the transmission wavelength is moved properly for each sweep step.

On that occasion there are chances that a moving amount of the transmission wavelength at a time is limited because of a restriction of a follow-up speed of the receiving station to follow the wavelength. In such cases, the time for convergence to the steady state can be made shorter in Embodiments 3 and 4 because one sweep step in Embodiments 3 and 4 is short.

(Embodiment 5)

The fifth embodiment of the present invention is next explained with reference to the drawings.

The present embodiment is different from Embodiments 1 to 4 as described above in that each station has two wavelength-variable filters for wavelength control. The present embodiment employs an analog circuit as the control circuit, and performs feedback control by the wobbling method.

Fig. 15 is a structural drawing of a wavelength control system in the transmitter of the present embodiment. Reference numeral 1303 designates a control circuit, which controls an output wavelength of a wavelength-variable light source 1303 and passing wavelengths of wavelength-variable filters 1307-1 and 1307-2 in order to avoid interference with another terminal station. Numeral 1302-1 denotes a drive circuit, which drives the wavelength-variable light source 1303, based on a signal from the control circuit 1301. Numeral 1303 is the wavelength-variable light source, which outputs light to an optical dividing element 1304. This light source can change the wavelength of the output light therefrom by control from the outside, for example like a semiconductor laser. The light source can also modulate, for example, the intensity of the output light in accordance with a transmission signal from the outside. Numeral 1304 denotes the optical dividing element, which divides the output light from the wavelength-variable light source 1303 into two beams and outputs them to the wavelength-variable filter 1307-1 and to an optical dividing / power multiplexing element 1308. Numer-

als 1307-1 and 1307-2 denote the wavelength-variable filters, which are filters that can change their wavelength regions of the transmitted light by external control, for example such as fiber Fabry-Perot filters. Numeral 1306-1 is a light receiving element, which receives the light from the wavelength-variable light source 1303, having been transmitted by the wavelength-variable filter 1307-1. Numeral 1305-1 denotes an amplifier, which amplifies a signal from the light receiving element 1306-1 and outputs it to the control circuit 1301. Numeral 1302-2 is a drive circuit, which drives the wavelength-variable filter 1307-1, based on a signal from the control circuit 1301. Numeral 1308 is the optical dividing / power multiplexing element, which outputs the output light from the optical dividing element 1304 to the transmission line and outputs received light from the transmission line to the wavelength-variable filter 1307-2. Numeral 1306-2 represents a light receiving element, which receives the light from the transmission line, having been transmitted by the wavelength-variable filter 1307-2. Numeral 1305-2 is an amplifier, which amplifies a signal from the light receiving element 1306-2 and outputs it to the control circuit 1301. Numeral 1302-3 is a drive circuit, which drives the wavelength-variable filter 1307-2, based on a signal from the control circuit 1301.

In the above arrangement, each of the optical dividing element 1304 and the optical dividing / power multiplexing element 1308 is constructed for example of a half mirror or a beam splitter.

The wavelength-variable light source 1303 may be the one as used in Embodiments 1 to 4.

In the present embodiment the wavelength-variable light source 1303 is also composed of the wavelength adjusting section for changing the wavelength of the output light and the output light modulating section for modulating the output light. In the case of a wavelength-variable DBR semiconductor laser, the DBR portion corresponds to the wavelength adjusting section and the active region to the output light modulating section. In the present embodiment, the drive circuit 1302-1 is connected to the wavelength adjusting section. Further, a transmission signal from the terminal equipment is input into the output light modulating section.

The present embodiment may also employ, for example, the FFP (fiber Fabry-Perot) type filters as the wavelength-variable filters 1307-1, 1307-2.

Let us suppose here that as an input voltage into the drive circuit 1302-1, -2, -3 increases, the wavelength of the wavelength-variable light source 1303 and the passing wavelengths of the wavelength-variable filters 1307-1, 1307-2 each change to the longer wavelength side. Further, when a same voltage is applied to the drive circuits 1302-2 and 1302-3, the passing wavelengths of the wavelength-variable filters 1307-1 and 1307-2 coincide with each other. Namely, the drive circuits 1302-2 and 1302-3 are arranged to absorb the difference in sweep characteristics of the passing wavelengths between the wavelength-variable filters 1307-1 and 1307-2.

Fig. 16 is a drawing to show the setup of the control circuit 1301 shown in Fig. 15. Numeral 1401 is a voltage sweep circuit, which outputs a control signal for determining the output wavelength of the wavelength-variable light source 1303 to the drive circuit 1302-1. Numeral 1402-1 is a feedback control circuit, which generates a control signal, based on a signal from the amplifier 1305-1 and a signal from the phase inversion circuit 1403, and outputs it to the drive circuit 1302-1. Numeral 1403 denotes a phase inversion circuit, which inverts the phase of the signal from the oscillator 1404 and outputs the inverted signal to feedback control circuit 1402-1. Numeral 1402-2 is a feedback control circuit, which generates a control signal, based on the signal from the amplifier 1305-1 and the signal from an oscillator 1404, and outputs it to a switch 1405-1. Numeral 1404 denotes the oscillator, which outputs a signal to the feedback control circuits 1402-2, 1402-3, phase inversion circuit 1403, and switches 1405-1, 1405-2. Numeral 1405-1 is a switch for switching two inputs, which outputs either one of a sum signal between the control signal from the feedback control circuit 1402-2 and the signal from the oscillator 1404 and a difference signal between the output signal from the switch 1405-2 and a signal from a constant voltage generation circuit 1406 to the drive circuit 1302-2 and to the switch 1405-2. Numeral 1406 is the constant voltage generation circuit, which generates a constant voltage and outputs it to the switches 1405-1 and 1405-2. Numeral 1405-2 is a switch for switching two inputs, which outputs either one of a sum signal between the control signal from the feedback control circuit 1402-3 and the signal from the oscillator 1404 and a sum signal between the output signal from the switch 1405-2 and the signal from the constant voltage generation circuit 1406 to the drive circuit 1302-3 and the switch 1405-1. Numeral 1402-3 denotes the feedback control circuit, which generates a control signal, based on the signal from the amplifier 1305-2 and the signal from the oscillator 1404 and outputs it to the switch 1405-2. Numeral 1407 designates a detection circuit, which determines upon transmission whether there exists a transmission wavelength of one other station in the proximity wavelength region of the transmission wavelength of the self station or not and outputs a signal indicating a result thereof to an ON/OFF control circuit 1408. Upon receiving, the detection circuit 1407 detects a receiving signal based on the signal from the amplifier 1305-2 and outputs it to the terminal equipment. Numeral 1408 is the ON/OFF control circuit, which controls ON/OFF of sweep of the voltage sweep circuit 1401, ON/OFF of feedback of the feedback control circuits 1402-1 to -3, and switch of inputs of the switches 1405-1, 1405-2. Numeral 1409-1 is an adder, which adds the output from the feedback control circuit 1402-2 to the output from the oscillator 1404 and outputs a result to the switch 1405-1. Numeral 1409-2 is also the adder, which adds an output from the feedback control circuit 1402-3 to the output from the oscillator 1404 and outputs a result to the switch 1405-2. Numeral 1409-3 is an adder, which adds the output from the switch 1405-1 to the output from the constant voltage generation circuit 1406 and outputs a result to the switch 1405-2. Numeral 1410 is a subtracter, which subtracts

the output from the constant voltage generation circuit 1406 from the output from the switch 1405-2 and outputs a result to the switch 1405-1.

A system for achieving the wavelength-multiplexing optical communication method of the present embodiment is the one shown in Fig. 5.

The setup of the optical transmitter-receiver portion of each terminal 302-1 to 302-n is the same as the one shown in Fig. 6.

Fig. 17 is a drawing to show a relative relation between the passing wavelengths of the wavelength-variable filters 1307-1, 1307-2 shown in Fig. 15 and the output wavelength of the wavelength-variable light source 1303. In the drawing, numeral 1501 indicates a wavelength transmission characteristic of the wavelength-variable filter 1307-1 and numeral 1502 a wavelength transmission characteristic of the wavelength-variable filter 1307-2. Further, λ_k represents the transmission wavelength of the wavelength-variable light source 1303 and the passing wavelength of the wavelength-variable filter 1307-1, and λ_1 the passing wavelength of the wavelength-variable filter 1307-2.

Figs. 18A to 18C show relations on the wavelength axis between the communicating wavelengths and the passing wavelengths of the wavelength filters where there are a plurality of terminal stations communicating by the present method. Here λ_1 to λ_{k-1} represent transmission wavelengths of other terminals. Further, λ_k and $\lambda_{k'}$ are transmission wavelengths of the self terminal (say a terminal 303-1). Numeral 1601 represents a transmitting spectrum of the wavelength-variable filter 1307-1 of the self terminal. Numeral 1602 indicates a transmitting spectrum of the wavelength-variable filter 1307-2 of the self terminal. Fig. 18A shows a case where the self terminal starts transmission, Fig. 18B a case where the self terminal detects a transmission wavelength of another terminal, and Fig. 18C a case where the transmission wavelength of the self terminal reaches the longest wavelength side of the wavelength range handled by itself.

Fig. 19 is a drawing to illustrate a state of the control of communication wavelengths where there are a plurality of terminals communicating by the present method. In the drawing, λ_1 to λ_m represent the transmission wavelengths of the respective terminals.

Fig. 22 is a drawing to illustrate the operation of the ON/OFF control circuit 1408 in the control circuit 1301 in the present embodiment.

Next explained is the operation upon transmission of the present embodiment having the above arrangement.

In the present embodiment, the transmitter 402 is connected through the optical dividing / power multiplexing element 401 to the transmission line. The setup of the wavelength control system enclosed in the transmitter 402 is shown in Fig. 15. In order to avoid interference and to effectively use the wavelengths, the control circuit 1301 controls the wavelength of the output light from the wavelength-variable light source 1303, i.e., the transmission wavelength, and the passing wavelengths of the wavelength-variable filters 1307-1, 1307-2 in the following manner.

For one terminal, Fig. 17 shows the relative relation among the transmission wavelength and the two passing wavelengths of the wavelength-variable filters. As shown in the drawing, the control circuit 1301 performs such control as to keep the passing wavelength of the wavelength-variable filter 1307-1 and the transmission wavelength λ_k always coincident with each other. Further, the control circuit controls the passing wavelengths of the wavelength-variable filters 1307-1 and 1307-2 so as to keep a difference between the passing wavelengths ($\Delta\lambda = \lambda_1 - \lambda_k$ in the drawing) always constant.

Figs. 18A to 18C show relations on the wavelength axis between the transmission wavelengths and the passing wavelengths of the wavelength-variable filters for plural terminals in communication by the present method.

Fig. 18A shows a case where a transmission signal of another terminal is not detected or where the intensity of the transmitted light by the wavelength-variable filter 1307-2 does not exceed a predetermined value. In this case, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-1 so as to follow up the transmission wavelength. At the same time, the control circuit controls the passing wavelength of the wavelength-variable filter 1307-2 so that it can follow up the passing wavelength of the wavelength-variable filter 1307-1 as keeping the wavelength difference $\Delta\lambda$ constant. Further, the control circuit continuously changes the transmission wavelength λ_k of the self terminal to the longer wavelength side.

A method for starting transmission of the self terminal may be selected from those as described in Embodiment 1.

It is also conceivable that the transmission wavelength of the self terminal reaches the longest wavelength side of the wavelength range handled by itself without detecting a transmission signal of any other terminal (Fig. 18C). For example, such a case may occur when the self terminal starts communication in a state where no other terminal is in communication in the present communication system. In this case, the control circuit 1301 stops changing the transmission wavelength to the further longer wavelength side. Specifically, the control circuit holds the output from the drive circuit 1302-1 for driving the wavelength-variable light source 1303.

Fig. 18B shows a case where a transmission signal of another terminal is detected, that is, where the intensity of the transmitted light by the wavelength-variable filter 1307-2 exceeds the predetermined value. The control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-2 so as to make it coincide with the transmission wavelength λ_{k-1} from another terminal. At the same time, the control circuit controls the passing wavelength of the wavelength-variable filter 1307-1 so as to make it follow up the passing wavelength of the wavelength-variable filter 1307-

2 as keeping the wavelength difference $\Delta\lambda$ constant. Further, the control circuit controls the transmission wavelength λ_k' so as to make it coincide with the passing wavelength of the wavelength-variable filter 1307-1.

This control forms an array of the transmission wavelengths from the respective terminals with the head on the longer wavelength side on the wavelength axis in the transmission line. Fig. 19 shows a state of the control. Here, let us suppose that m terminals of 303-1 to 303- m are transmitting respective signals, using their own wavelengths of λ_1 to λ_m .

Also in this embodiment, when a certain terminal ends its transmission, a gap appears in the array of transmission wavelengths. However, since the gap is bridged by moving an array of transmission wavelengths located on the shorter wavelength side than the gap to the longer wavelength side, the wavelength region can be effectively used.

Explained in further detail is the configuration and operation of the control circuit 1301 performing the wavelength control as described above.

This control circuit is arranged to switch the control methods of wavelengths in accordance with determination of the ON/OFF control circuit, based on a signal from the terminal equipment or a signal from the detection circuit 1407, as discriminating the following two cases from each other: (1) a case where a transmission signal of another terminal is not detected; (2) a case where a transmission signal of another terminal is detected. Fig. 22 shows the control performed by the ON/OFF control circuit for the respective cases. The operation in the respective cases is explained in order.

(1) The case where a transmission signal of another terminal is not detected

This corresponds to the case of Fig. 18A. The control circuit 1301 controls the wavelength-variable light source 1303 to output a signal from the terminal equipment as gradually increasing the transmission wavelength. For that, the voltage sweep circuit 1401 outputs to the drive circuit 1302-1 a signal to gradually increase the voltage as a wavelength control signal, thereby increasing the transmission wavelength of the wavelength-variable light source 1303. The feedback control circuit 1402-1 is not actuated.

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-1 so as to make it coincide with the transmission wavelength of the wavelength-variable light source 1303. For that, the feedback control circuit 1402-2 is actuated to generate a control signal for the wavelength-variable filter 1307-1, based on the signal from the amplifier 1305-1 (a light signal transmitted by the wavelength-variable filter 1307-1). The switch 1405-1 is on on the side A to output the control signal as described above to the drive circuit 1302-2, thereby controlling the passing wavelength of the wavelength-variable filter 1307-1.

In the present embodiment each feedback control circuit 1402-1 to 1402-3 is arranged to compare an input signal with a modulation signal from a modulator 204 for effecting fine modulation, and to output a control signal which is positive if the two signals have the same phase or negative if the signals have the opposite phases, as a control signal. When the output from the modulator is used as a modulation signal and the intensity signal of the transmitted light by the wavelength-variable filter (which slightly modulates the passing wavelength by the modulation signal) is used as an input signal as in the present embodiment, a positive output is obtained when the passing wavelength is shifted to the shorter wavelength side than the transmission wavelength or a negative output is obtained when the passing wavelength is shifted to the longer wavelength side. This is because the passing wavelength of the wavelength-variable filter is also finely modulated. The passing wavelength can be made coincide with the transmission wavelength by feeding the above output back to the passing wavelength of the wavelength-variable filter. The principle and constitution of such feedback control circuit and filter control system are explained in detail for example in Japanese Laid-open Patent Application No. 1-177518.

Further, the wavelength control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-2 to keep the difference $\Delta\lambda$ of the center passing wavelength from the wavelength-variable filter 1307-1 always constant. For that, the feedback control circuit 1402-2 is actuated and the output therefrom is added to the output from the constant voltage generation circuit 1406 to generate a control signal for the wavelength-variable filter 1307-2. Here, a voltage generated by the constant voltage generation circuit corresponds to a wavelength of the difference between the passing wavelengths of the two wavelength-variable filters. The switch 1405-2 is on on the side A, and the control signal as described above is output to the drive circuit 1302-3, thereby controlling the passing wavelength of the wavelength-variable filter 1307-2. The feedback control circuit 1402-3 is not actuated.

The detection circuit 1407 is monitoring the signal from the amplifier 1305-2. When the signal exceeds a predetermined level, the detection circuit sends a control signal of "detected" to the ON/OFF control circuit 1408. This level is set lower than the level of the signal output from the amplifier 1305-2 when the transmission wavelength of the other terminal approaches the transmission wavelength of the self terminal up to immediately before causing interference.

A special case conceivable is a case where the transmission wavelength of the self terminal is located on the longest wavelength side among the transmission wavelengths on the transmission line. This corresponds to the case of Fig. 18C. The output voltage of the voltage sweep circuit 1401 is arranged to saturate at a certain value. This value is set on the as longer wavelength side as possible in a common portion of the wavelength-variable ranges of the wavelength-variable light source and the two wavelength-variable filters.

(2) The case where the transmission signal of another terminal is detected

This corresponds to the case of Fig. 18B. The control circuit 1301 controls the wavelength-variable light source 1303 to make the transmission-wavelength coincide with the passing wavelength of the wavelength-variable filter 1307-1. For that, the control circuit keeps the output from the voltage sweep circuit at the same magnitude as that at the time of change from the state of the case (1). Further, the feedback control circuit 1402-1 is actuated to generate a control signal for the wavelength-variable light source 1303, based on the signal from the amplifier 1305-2.

The control circuit 1301 also controls the passing wavelength of the wavelength-variable filter 1307-1 to keep a wavelength difference from the passing wavelength of the wavelength-variable filter 1307-2 always constant. For that, the switches 1405-1 and 1405-2 are made on on the side B. The feedback control circuit 1402-3 is actuated, an output from the constant voltage generation circuit 1406 is subtracted from the output from the feedback control circuit, and thereafter the result is output to the drive circuit 1302-2 to change the passing wavelength of the wavelength-variable filter 1307-1. The feedback control circuit 1402-2 is not actuated.

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-2 to make the passing wavelength coincide with a transmission wavelength of another terminal located on the longer wavelength side than and closest to the transmission wavelength of the self terminal out of the transmission wavelengths of the other terminals. This wavelength corresponds to λ_{k-1} in Fig. 18B. For that, the feedback control circuit 1402-3 is actuated to generate a control signal for the wavelength-variable filter 1307-2, based on the signal from the amplifier 1305-2 (the light signal transmitted by the wavelength-variable filter 1307-2). The switch 1405-2 is made on on the side B, and the control signal as described above is output to the drive circuit 1302-3, thereby controlling the passing wavelength of the wavelength-variable filter 1307-2.

Similarly as in the case of (1), the detection circuit 1407 is monitoring the signal from the amplifier 1305-2, and sends a control signal of "not detected" to the ON/OFF control circuit 1408 when the signal becomes lower than the predetermined level.

The operation upon receiving is the same as in Embodiments 1 to 4.

Applying the optical transmitter-receiver device 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, a transmitting terminal can continue transmitting signals as avoiding interference, and a receiving terminal can continue receiving signals without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, it is not necessary to achieve precise stability of the transmission wavelength of each station.

(Embodiment 6)

The sixth embodiment of the present invention is next explained with reference to the drawings.

The basic constitution and operation of the present embodiment are the same as those of Embodiment 5. However, the present embodiment realizes the control of the wavelength-variable light source and wavelength-variable filters in the transmitter by using a control circuit having a construction different from that in Embodiment 5. Specifically, a digital circuit is used as the control circuit, and thus, feedback control is carried out by digital control.

The schematic drawing of a system for achieving the wavelength-multiplexing optical communication method of the present embodiment is shown in Fig. 5, and the schematic drawing of the optical transmitter-receiver portion of each terminal in Fig. 15. The operation of each portion is the same as in Embodiment 5, and thus, the description is omitted herein.

Fig. 20 is a drawing to show the setup in the present embodiment, of the control circuit 1301 shown in Fig. 15.

Numeral 1801 designates a CPU, which receives a control signal from terminal equipment, receives data from A/D converters 1803-1 and 1803-2, and sends data to D/A converters 1802-1 to 1802-3 after completion of necessary calculation. Numeral 1802-1 is a converter, which outputs a control signal for determining the transmission wavelength of the wavelength-variable light source 1303 to the drive circuit 1302-1, based on the data from the CPU 1801. Numeral 1802-2 is a D/A converter, which outputs a control signal for determining the passing wavelength of the wavelength-variable filter 1307-1 to the drive circuit 1302-2, based on the data from the CPU 1801. Numeral 1802-3 is a D/A converter, which outputs a control signal for determining the passing wavelength of the wavelength-variable filter 1307-2 to the drive circuit 1302-3, based on the data from the CPU 1801. Numeral 1803-1 is an A/D converter, which converts the signal obtained from the amplifier 1305-1 into a digital signal and outputs it to the CPU 1801. Numeral 1803-2 is an A/D converter, which converts the signal obtained from the amplifier 1305-2 into a digital signal and outputs it to the CPU 1801.

Figs. 21A to 21C are drawings to illustrate the operation of the control circuit 1301 in the present embodiment. Fig. 21A shows a time change of transmission spectrum of the wavelength-variable filter, Fig. 21B a time change of a numerical value sent from the control circuit to the D/A converter, and Fig. 21C a time change of a numerical value received by the control circuit from the A/D converter.

Next explained in detail is the operation of the control circuit 1301 in the present embodiment, having the above arrangement. Also in this control circuit, the operation is different between the following two cases: (1) the case where a transmission signal of another terminal is not detected; (2) the case where a transmission signal of another terminal is detected. The operation states are switched by the CPU 1801, judging either based on the signal from the terminal equipment and the signal from the A/D converter 1803-2. The two cases will be explained in order.

(1) The case where a transmission signal of another terminal is not detected

This corresponds to the case of Fig. 18A. The control circuit 1301 controls the wavelength-variable light source 1303 to output the signal from the terminal equipment to the transmission line as gradually increasing the transmission wavelength. For that, the CPU 1801 controls the D/A converter 1802-1 to gradually increase the output therefrom. The output from the D/A converter 1802-1 is sent to the drive circuit 1302-1 to increase the wavelength of the output light from the wavelength-variable light source 1303.

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-1 to make it coincide with the transmission wavelength of the wavelength-variable light source 1303. Figs. 21A to 21C are drawings to illustrate it. In Fig. 21A, numeral 1901 represents the transmission wavelength, and 1902-1 to 1902-5 transmission spectra of the filter. As shown in Fig. 21A, the passing wavelength of the wavelength-variable filter 1307-1 is swept in a certain range and the sweep start wavelength is controlled so as to keep the transmission wavelength of the wavelength-variable light source 1303 within the range.

This can be realized for example by the following control of CPU 1801. The CPU 1801 sends numerical data to the D/A converter 1802-2 to increase the value by Δn every very short period Δt . Here, the numerical value sent to the D/A converter 1802-2 corresponds to an output voltage thereof and the passing wavelength of the wavelength-variable filter 1307-1, and Δn to the minimum change $\Delta \lambda_s$ of the passing wavelength of the wavelength-variable filter 1307-1. At the same time, the CPU 1801 monitors the numerical value output from the A/D converter 1803-1. Here, the numerical value from the A/D converter 1803-1 corresponds to the intensity of the light transmitted by the wavelength-variable filter 1307-1.

As the CPU 1801 increases the numerical value sent to the D/A converter 1802-2, the numerical value obtained from the A/D converter 1803-1 comes to have a peak when the passing wavelength of the wavelength-variable filter 1307-1 comes to coincide with the transmission wavelength of the wavelength-variable light source 1303. Once a peak is found, the numerical value sent to the D/A converter 1802-2 is swept within a proper range, and then the sweep start value is controlled always to find a peak. Fig. 21B shows an example of the time change of the numerical value sent from the CPU 1801 to the D/A converter 1802-2 when the above control is performed. Fig. 21C shows a time change of the numerical data obtained from the A/D converter 1803-1 by the CPU 1801 on that occasion.

The minimum unit Δn of the change of the numerical value sent to the D/A converter is preliminarily set to a value suitable for the CPU finding a peak, taking the filter finesse and range of sweep into consideration.

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-2 to keep the difference $\Delta \lambda$ of the passing wavelength from the wavelength-variable filter 1307-1 always constant. The CPU 1801 realizes the above control by sending a numerical value $N + \Delta N$ obtained by adding a constant ΔN to the numerical data N sent to the D/A converter 1802-2, to the D/A converter 1802-3. Here, the constant ΔN corresponds to the wavelength of the difference between the two passing wavelengths of the wavelength-variable filters. The value is preliminarily set to a magnitude not causing interference upon receiving signals.

Further, a determination as to whether a transmission signal from another terminal is detected upon transmission near the transmission wavelength of the self terminal is carried out as follows. The CPU 1801 always monitors the numerical data of the output from the A/D converter 1803-2, and transfers the control into the state of (2) as described below when it exceeds a predetermined value. This value is set to a lower value than the numerical value output from the A/D converter 1803-2 when the transmission wavelength of the other terminal approaches the transmission wavelength of the self terminal up to just before causing interference.

The upper limit is set for the numerical data sent from the CPU 1801 to the D/A converter 1802-1 for the case where the transmission wavelength of the self terminal is located at the longest wavelength side out of the transmission wavelengths on the transmission line, that is, for the case corresponding to Fig. 18C. This value is set on the as longer wavelength side as possible in a common portion of the wavelength-variable ranges of the wavelength-variable light source and two wavelength-variable filters.

(2) The case where a transmission signal of another terminal is detected

This corresponds to the case of Fig. 18B. The control circuit 1301 controls the transmission wavelength of the wavelength-variable light source 1303 to make it coincide with the passing wavelength of the wavelength-variable filter 1307-1. More precisely, sweeping the transmission wavelength of the wavelength-variable light source 1303 within a certain range, the transmission wavelength of the wavelength-variable light source is controlled so as to keep the passing

wavelength of the wavelength-variable filter 1307-1 within the range. This can be realized by the CPU 1801 performing the control similar to the case of (1). Namely, sweeping the numerical data sent to the D/A converter 1802-2, the numerical value from the A/D converter 1803-1 is monitored. Once a peak corresponding to the transmission wavelength is found, the numerical data sent to the D/A converter 1802-2 is swept in an appropriate range to control the transmission wavelength, in other words, the numerical data sent to the D/A converter 1802-1 so as to always find a peak within the range.

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-1 to keep the difference $\Delta\lambda$ of the passing wavelength from the wavelength-variable filter 1307-2 always constant. The CPU 1801 realizes the above control by sending a numerical value $N - \Delta N$ obtained by subtracting a constant ΔN preliminarily set from the numerical data N sent to the D/A converter 1802-3, to the D/A converter 1802-2. Here, the constant ΔN corresponds to a wavelength of the difference between the passing wavelengths of the two wavelength-variable filters, which is equal to the constant ΔN used in the case of (1).

Further, the control circuit 1301 controls the passing wavelength of the wavelength-variable filter 1307-2 to make it coincide with a transmission wavelength of another terminal on the longer wavelength side than and closest to the transmission wavelength of the self terminal out of the transmission wavelengths of the other terminals. This wavelength corresponds to λ_{k-1} in Fig. 18B. This can be realized by the CPU 1801 performing control very similar to that in the case of (1). Namely, sweeping the numerical data sent to the D/A converter 1802-3, the numerical value from the A/D converter is monitored. Once a peak is found corresponding to the transmission wavelength from the other terminal, the numerical value sent to the D/A converter 1802-3 is swept within a suitable range and the sweep start value is controlled so as to always find a peak within the range.

The CPU 1801 always monitors the numerical data as being the output from the A/D converter 1803-2, similarly as in the case of (1), and control is transferred to the state of (1) as discussed previously when the numerical data becomes lower than the predetermined value.

Applying the optical transmitter-receiver unit 303 provided with the transmitter 402 and receiver 403 performing the above wavelength control to the optical communication system of Fig. 5, a transmitting terminal can continue transmission as avoiding interference, and a receiving terminal can continue receiving signals without being out of tuning. Since the transmission wavelengths of the respective stations are arranged at suitable intervals on the wavelength axis in the transmission line, the wavelength multiplicity can be increased. Further, it is not necessary to achieve precise stability of the transmission wavelength of each station.

Since Embodiments 5 and 6 detect the transmission wavelength of the self station and the adjacent wavelength independently of each other, repetition of sweep steps becomes unnecessary, and high-speed control becomes possible. This permits the system to quickly transfer to the steady state and increases the response speed to a change of the wavelength.

(Other embodiments)

The essence of the present invention was explained using the above six embodiments, but applications of the present invention are not limited to these embodiments.

The above embodiments were explained as examples of the communication system using the star coupler as shown in Fig. 5. The present invention can be, however, applied to communication systems of any type including the bus type, the star type, the loop type, and the other types as long as the wavelength-multiplexing optical communication is carried out.

Although the above embodiments used the optical fibers as transmission media, the present invention can be applied to the cases performing the wavelength-multiplexing optical communication for example through the space.

The above embodiments used the DBR type semiconductor laser as a wavelength-variable light source, but any light source can be applied as the light source of the present invention as long as the wavelength thereof can be changed and the intensity modulation or the frequency modulation is possibly applied thereto.

The above embodiments used the FFP type filter as the wavelength-variable filter, but any filter that can similarly change the passing wavelength can be applied as the filter in each embodiment.

Further, the above embodiments were explained as defining the longer wavelength side as the head wavelength side and the shorter wavelength side as the tail wavelength side. Namely, when each station does not detect a transmission wavelength of another station, such control is effected that the transmission wavelength of the self station is gradually changed to the longer wavelength side. In this case, the longer wavelength side is the head of the array formed of the transmission wavelengths of the respective stations on the wavelength axis. In contrast, another possible arrangement is such that the shorter wavelength side is defined as the head wavelength side and the longer wavelength side as the tail wavelength side. It is a matter of course in that case that detection of the transmission wavelength of another station is carried out on the shorter wavelength side of the transmission wavelength of the self station. In this case, the shorter wavelength side is the head of the array formed of the transmission wavelengths of the respective stations on the wavelength axis.

For determining whether the longer wavelength side or the shorter wavelength side should be defined as the head, characteristics of the light source can be taken into consideration. For example, when the DFB type semiconductor laser (DFB-LD) is used as the light source, currents injected contribute to the both quantity of light and wavelength because diffraction grating and active layer exist in all region in DFB-LD. Among others, single-electrode DFB-LDs or multi-electrode DFB-LDs with great contribution of thermal effect exhibit coincidence between directions of increase or decrease of light quantity and wavelength against current. Namely, oscillation starts with an increase of current, and the oscillation wavelength gradually shifts to the longer wavelength side as oscillation becomes stabilized. The control of oscillating from the shorter wavelength side of the wavelength range and shifting the wavelength to the longer wavelength side corresponds to an increase of current in the cases of the above devices. When the other wavelengths already existing in the network are aligned from the longer wavelength side at this time, emission of light can be started without interference with the wavelengths by simply increasing the current.

In the case of a light source whose oscillation shifts to the shorter wavelength side as oscillation becomes stabilized, contrary to the above example, the head is desired to be located on the shorter wavelength side.

In the above embodiments, each station transfers a signal, using the intensity modulation. However, the signals can be transmitted using the FSK (Frequency Shift Keying) modulation. When transmission is carried out based on the FSK modulation, there exist two wavelengths transmitted, mark wavelength and space wavelength. The CPU 201 sweeps the passing wavelength of the wavelength-variable filter to detect two peaks corresponding to the mark and space wavelengths, and can perform the same control as in Embodiment 2, by giving a focus on either one.

In Embodiment 3, the control circuit 101 repeated the sweep of the passing wavelength of the wavelength-variable filter as alternating the directions thereof in the proximity wavelength region of λ_k in order to obtain the wavelength difference $\Delta\lambda_c$ between the transmission wavelength of the self station λ_k and the transmission wavelength of the other station λ_{k-1} .

It is, however, possible to employ such a control method that the sweep of the passing wavelength in the proximity wavelength region of λ_k , for obtaining $\Delta\lambda_c$ is repetitively carried out only in one direction. An example of the control method is such sequential operation that the passing wavelength is set on the shorter wavelength side than λ_k , the passing wavelength is swept to the longer wavelength side to detect λ_k , λ_{k-1} , then $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ is calculated, λ_k is controlled so that $\Delta\lambda_c$ may become equal to the predetermined value $\Delta\lambda_{c0}$, and the passing wavelength is again set on the shorter wavelength side than λ_k .

In Embodiment 4, the control circuit 101 repeated the sweep of the passing wavelength of the wavelength-variable filter in the proximity wavelength region of λ_{k-1} as alternating the directions of the sweep in order to obtain the wavelength difference $\Delta\lambda_c$ between the transmission wavelength of the self station λ_k and the transmission wavelength of the other station λ_{k-1} .

It is, however, possible to employ such a control method that the sweep of the passing wavelength in the proximity wavelength region of λ_{k-1} , for obtaining $\Delta\lambda_c$, is repetitively carried out only in one direction. An example of the control method is such sequential operation that the passing wavelength is set on the shorter wavelength side than λ_k , the passing wavelength is swept to the longer wavelength side to detect λ_k , then λ_{k-1} , $\Delta\lambda_c = \lambda_{k-1} - \lambda_k$ is calculated, λ_k is controlled so that $\Delta\lambda_c$ may become equal to the predetermined value $\Delta\lambda_{c0}$, and the passing wavelength is again set on the shorter wavelength side than λ_k .

The present invention as explained above can provide the wavelength-multiplexing optical communication method having the simple configuration and very high wavelength multiplicity without a need to perform precise temperature control or control of emission wavelength for light emitting unit in the wavelength-multiplexing optical communication method.

In a wavelength-multiplexing communication system, an optical transmitter detects at least either one wavelength of a transmission wavelength of a self optical transmitter and a wavelength adjacent to the transmission wavelength of the self optical transmitter on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter by a wavelength-variable band-pass filter capable of changing a passing wavelength thereof, and controls the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto may become a predetermined wavelength spacing.

Claims

1. A transmission wavelength control method in an optical transmitter used in an optical communication system for performing wavelength-multiplexing communication, comprising a step of: in a transmission state, detecting at least either one of a transmission wavelength of a self optical transmitter and a wavelength adjacent to said transmission wavelength of the self optical transmitter on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter, and controlling the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto may become a

predetermined wavelength spacing,

wherein said detecting of wavelength is carried out using a wavelength-variable band-pass filter capable of sweeping a passing wavelength thereof.

- 5 2. The method according to Claim 1, wherein said detecting at least either one wavelength of the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto is carried out using a common wavelength-variable band-pass filter.
- 10 3. The method according to Claim 2, wherein in a steady state in which said wavelength spacing is controlled at said predetermined wavelength spacing and in one sweep step of said wavelength-variable filter, the both wavelengths of said transmission wavelength of the self optical transmitter and said wavelength adjacent thereto are detected.
- 15 4. The method according to Claim 2 or 3, wherein during a period of approaching a steady state in which said wavelength spacing is controlled at said predetermined wavelength spacing and in one sweep step of said wavelength-variable filter, the both wavelengths of said transmission wavelength of said self optical transmitter and said wavelength adjacent thereto are detected.
- 20 5. The method according to Claim 2 or 3, wherein during a period of approaching a steady state in which said wavelength spacing is controlled at said predetermined wavelength spacing and in one sweep step of said wavelength-variable filter, either one wavelength of said transmission wavelength of said self optical transmitter and said wavelength adjacent thereto is detected.
- 25 6. The method according to either one of Claims 2 to 5, wherein upon detecting at least either one wavelength of the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto using said wavelength-variable band-pass filter, either a sweep step of gradually increasing the passing wavelength of said wavelength-variable band-pass filter or a sweep step of gradually decreasing said passing wavelength is repeated.
- 30 7. The method according to either one of Claims 2 to 5, wherein upon detecting at least either one wavelength of the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto using said wavelength-variable band-pass filter, sweep steps of gradually increasing and gradually decreasing the passing wavelength of said wavelength-variable band-pass filter are alternately repeated.
- 35 8. The method according to Claim 1, wherein separate wavelength-variable band-pass filters are used each in detecting the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto.
- 40 9. The method according to Claim 8, wherein a spacing between passing wavelengths of said respective, separate, wavelength-variable band-pass filters is said predetermined wavelength spacing.
- 45 10. The method according to Claim 9, wherein said controlling step comprises in a period of approaching a steady state in which said wavelength spacing is controlled at said predetermined wavelength spacing,
 - a step of making either one wavelength of the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto coincide with a passing wavelength of either one wavelength-variable band-pass filter out of said separate wavelength-variable band-pass filters; and
 - a step of controlling the transmission wavelength of the self optical transmitter as maintaining said coincident state, to move said transmission wavelength on the wavelength axis, thereby making the other wavelength out of said transmission wavelength of the self optical transmitter and said wavelength adjacent thereto coincide with the passing wavelength of the other wavelength-variable band-pass filter out of said separate wavelength-variable band-pass filters.
- 50 11. The method according to Claim 10, wherein said controlling step comprises a step of, in the steady state in which said wavelength spacing is controlled at said predetermined wavelength spacing, maintaining a state in which said transmission wavelength of the self optical transmitter and said wavelength adjacent thereto are coincident with the respective passing wavelengths of said separate wavelength-variable band-pass filters.
- 55 12. The method according to Claim 10 or 11, wherein in order to maintain the state in which the wavelengths on the wavelength axis are coincident with the passing wavelengths of said wavelength-variable band-pass filters, said wavelength-variable band-pass filters are controlled by analog control.

13. The method according to Claim 12, wherein said wavelength-variable band-pass filters are subjected to feedback control by the wobbling method.

14. The method according to Claim 10 or 11, wherein in order to maintain the state in which the wavelengths on the wavelength axis are coincident with the passing wavelengths of said wavelength-variable band-pass filters, said wavelength-variable band-pass filters are controlled by digital control.

15. The method according to Claim 14, wherein said wavelength-variable band-pass filters are subjected to feedback control by digital control.

16. The method according to either one of Claims 1 to 15, further comprising:
a step of setting a transmission start region at an end portion on an opposite side to either said longer wavelength side or said shorter wavelength side, in a wavelength region in which the self optical transmitter can perform transmission, starting the transmission in said transmission start region upon start of transmission, and interrupting the transmission when the wavelength spacing between the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto in said transmission start region becomes the predetermined wavelength spacing.

17. The method according to either one of Claims 1 to 15, further comprising:
a step of, upon start of transmission, starting the transmission after confirming that there is no other wavelength at least in said predetermined wavelength spacing at the end portion on the opposite side to either said longer wavelength side or said shorter wavelength side, in the wavelength region where the self optical transmitter can perform transmission.

18. An optical communication method in an optical communication system for performing wavelength-multiplexing communication by connecting a plurality of terminal stations each having their own optical transmitters, comprising a step of:

using the transmission wavelength control method as set forth in either one of Claims 1 to 17, in an optical transmitter of a terminal station in a communication state;

whereby transmission wavelengths of the optical transmitters of the plural terminal stations are wavelength-multiplexed in order of transmission starts from either said longer wavelength side or said shorter wavelength side.

19. An optical transmitter used in an optical communication system for performing wavelength-multiplexing communication, comprising:

transmission means arranged as capable of changing a transmission wavelength;

wavelength detecting means capable of detecting the transmission wavelength of the self optical transmitter and a wavelength adjacent thereto on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter; and

means for, in a transmission state, controlling said transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and said wavelength adjacent thereto may become a predetermined wavelength spacing, based on a result obtained when said wavelength-variable band-pass filter detects at least either one wavelength of the transmission wavelength of the self optical transmitter and the wavelength adjacent to the transmission wavelength of the self optical transmitter on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter;

wherein said wavelength detecting means is a wavelength-variable band-pass filter capable of sweeping a passing wavelength thereof.

20. The transmitter according to Claim 19, wherein said wavelength-variable band-pass filter is one wavelength-variable band-pass filter, said one wavelength-variable band-pass filter detecting the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter.

21. The transmitter according to Claim 19, wherein said wavelength-variable band-pass filter is two wavelength-variable band-pass filters, said two separate wavelength-variable band-pass filters each detecting the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto on the wavelength axis either on the longer wavelength side or on the shorter wavelength side than the transmission wavelength of the self optical transmitter.

22. An optical transmitter-receiver apparatus used in an optical communication system for performing wavelength-multiplexing communication, comprising:

the optical transmitter as set forth in either one of Claims 19 to 21; and

an optical receiver comprising:

receiving means for receiving a light signal to be received by the self optical transmitter-receiver apparatus from a light signal input thereinto as following up a change in a wavelength of said light signal.

23. An optical communication system for performing wavelength-multiplexing communication by connecting a plurality of terminal stations each having their own optical transmitters:

wherein said each optical transmitter is the optical transmitter as set forth in either one of Claims 19 to 21.

24. The system according to Claim 23, wherein said terminal station further has an optical receiver comprising:

receiving means for receiving a light signal to be received by the self optical transmitter-receiver apparatus from a light signal input thereinto as following up a change in a wavelength of said light signal.

FIG. 1
PRIOR ART

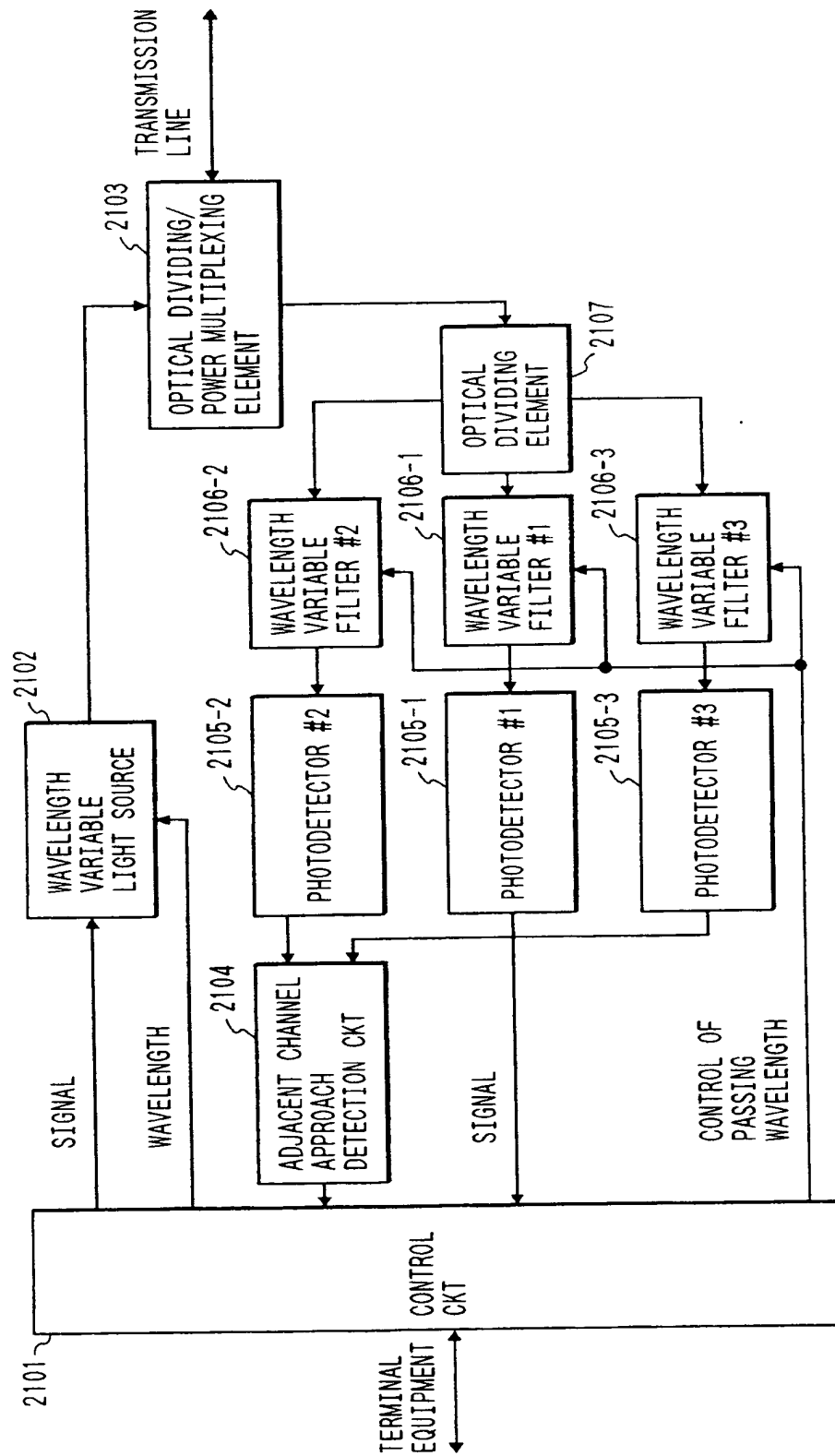


FIG. 2
PRIOR ART

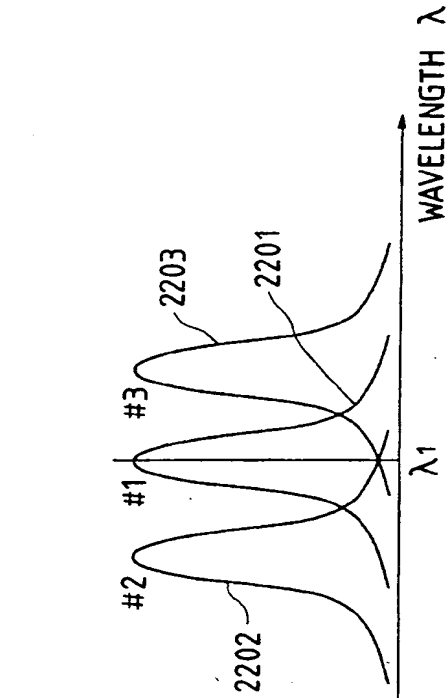


FIG. 4

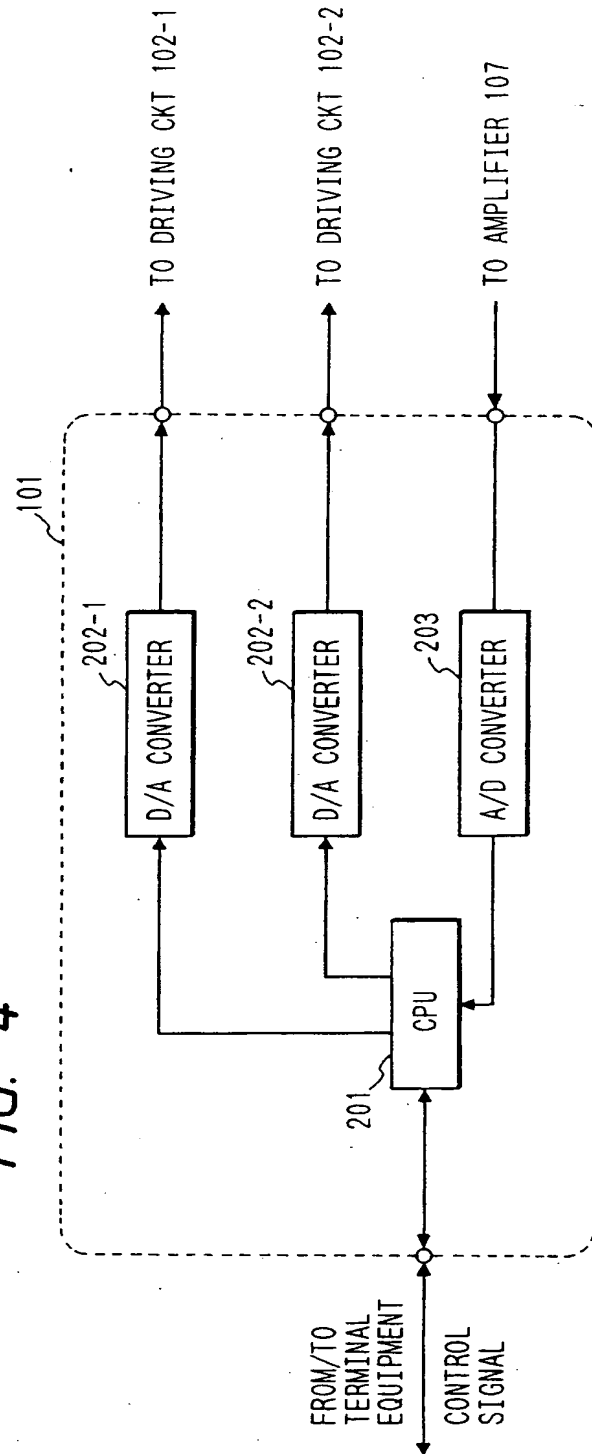


FIG. 3

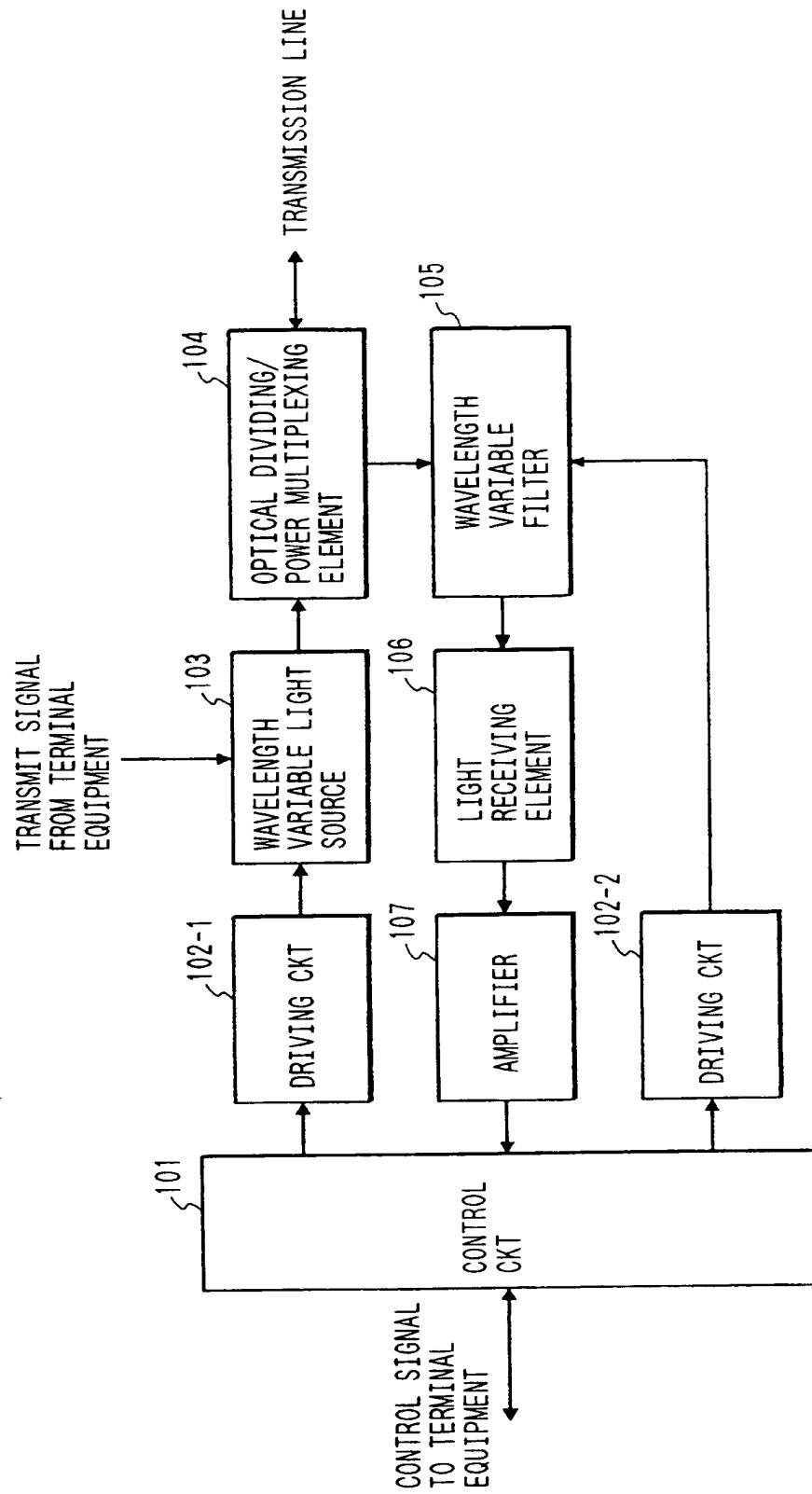


FIG. 5

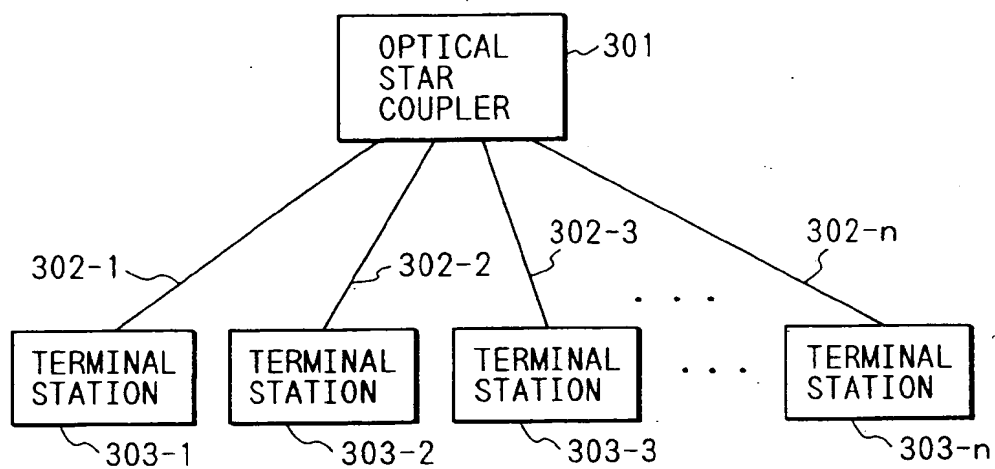


FIG. 6

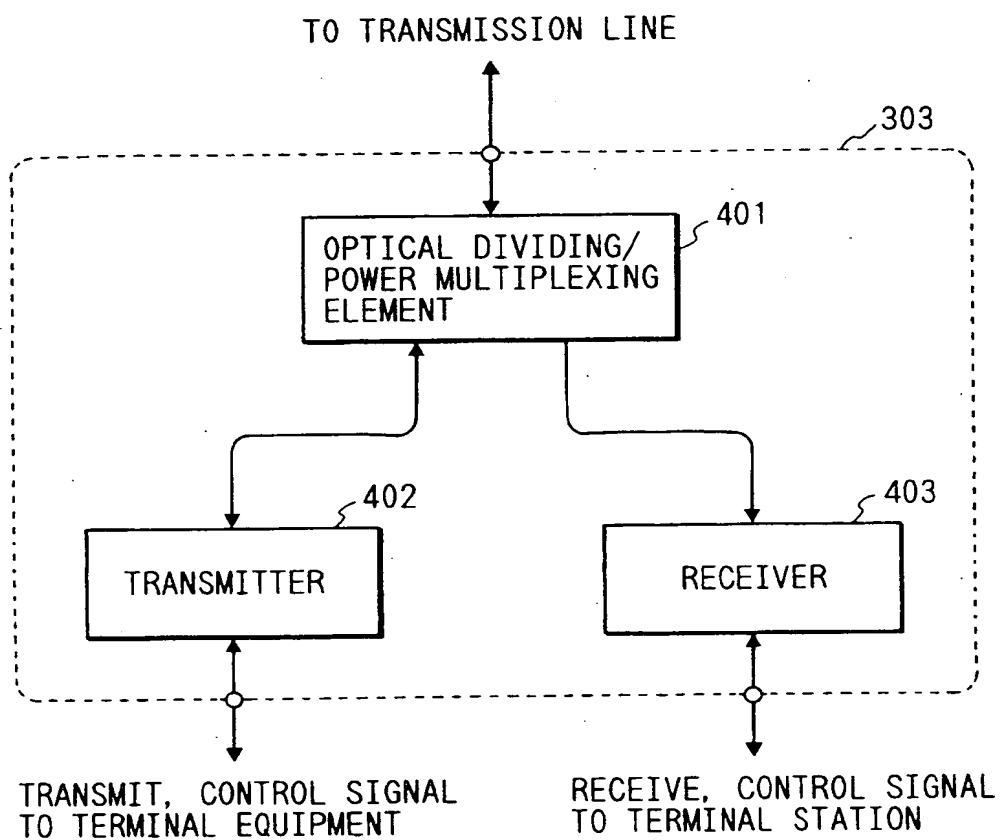


FIG. 7A

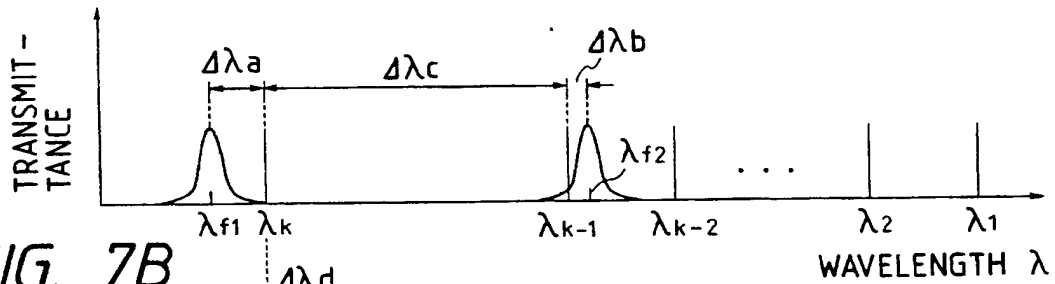


FIG. 7B

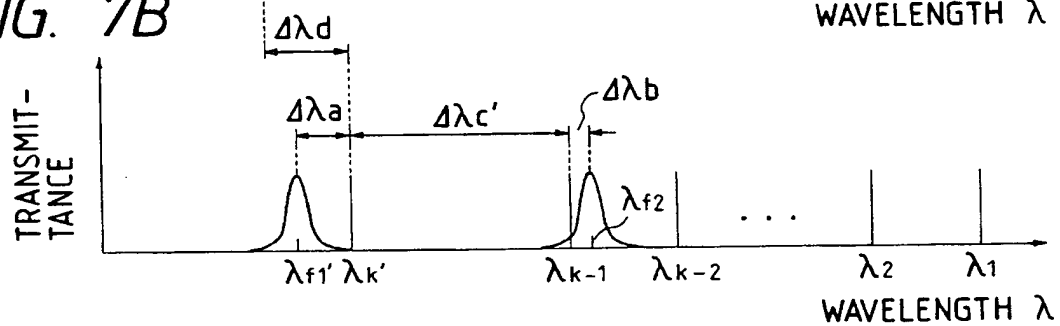


FIG. 7C

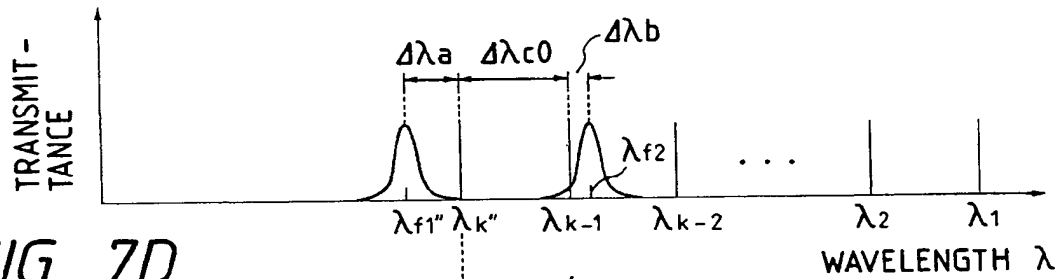


FIG. 7D

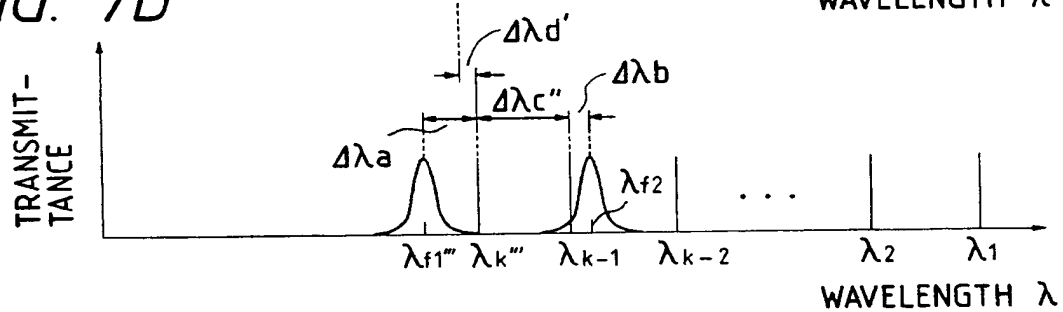


FIG. 8A

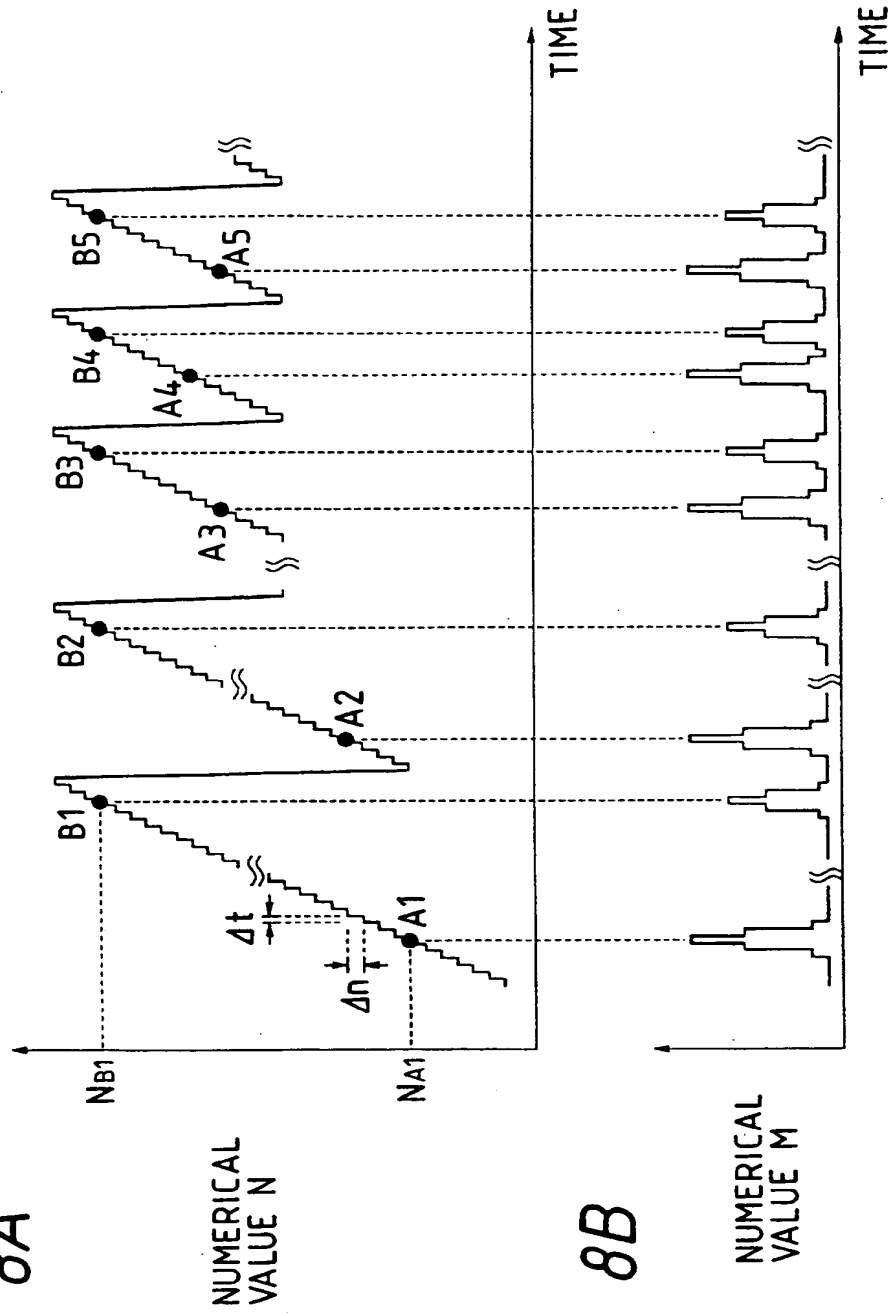


FIG. 8B

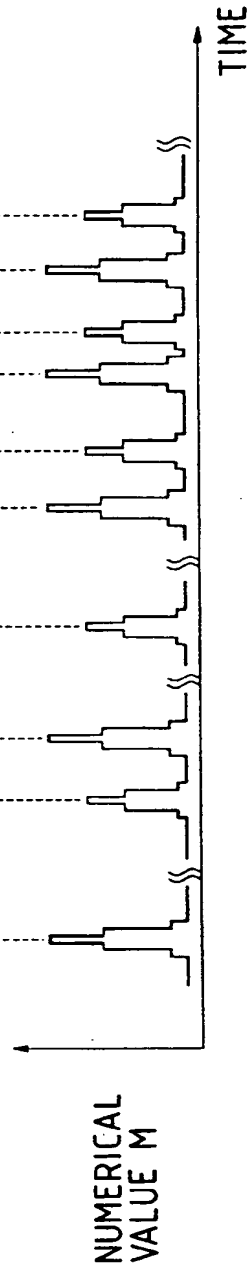


FIG. 9

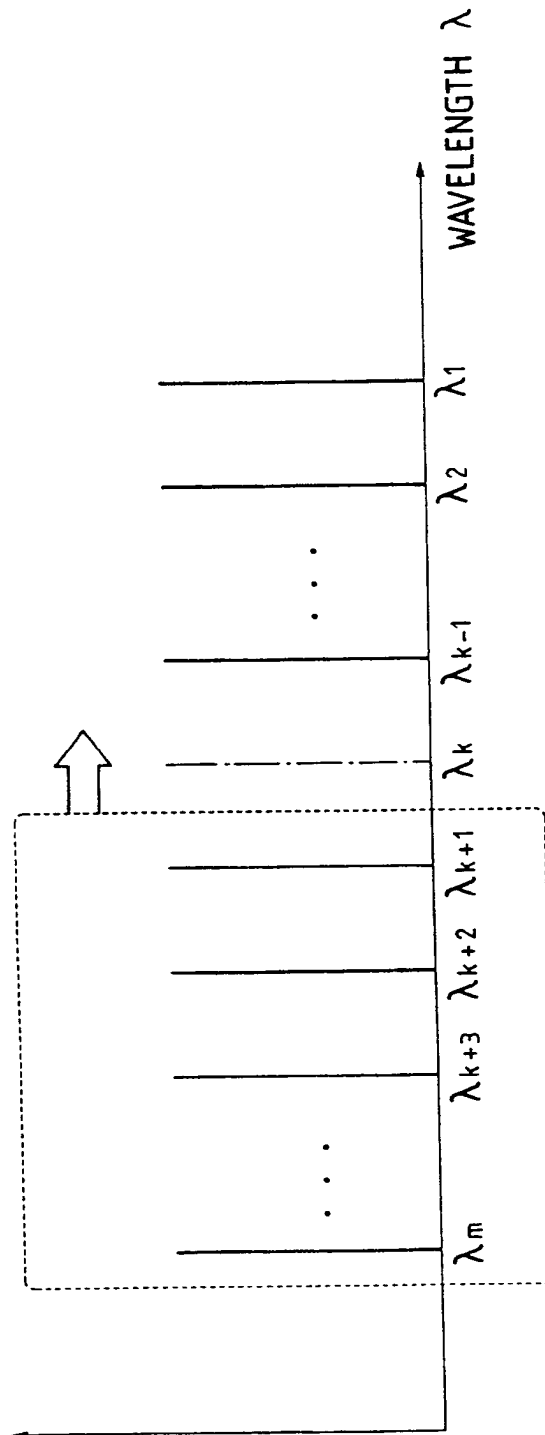


FIG. 10A

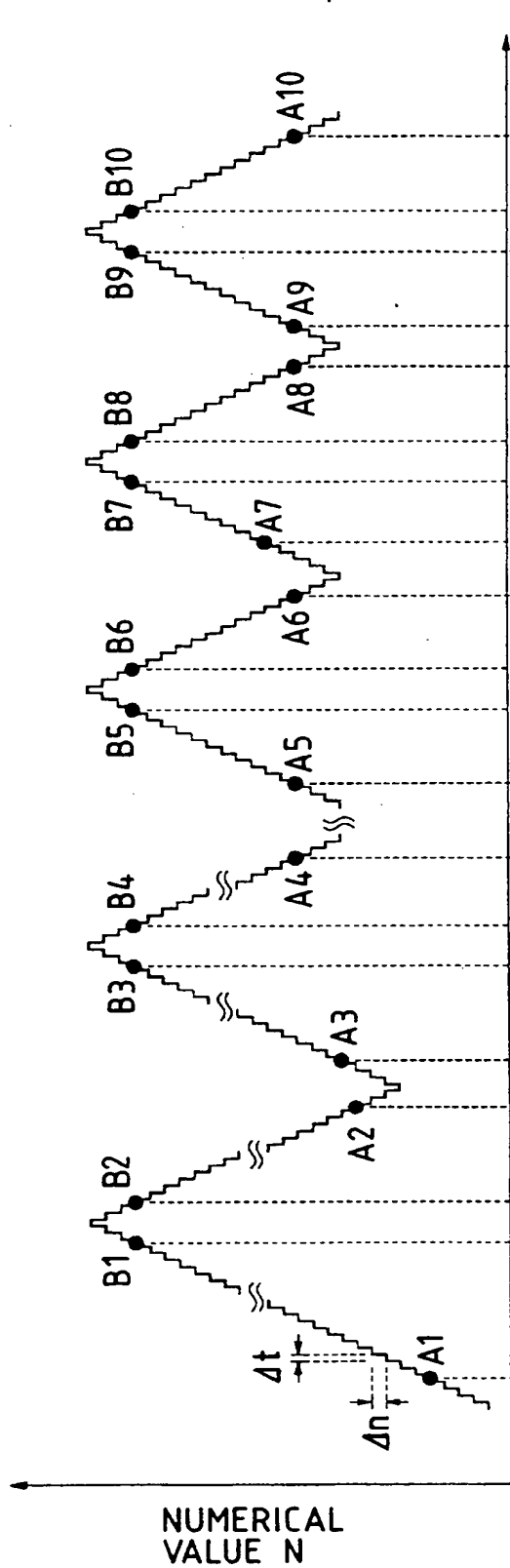


FIG. 10B

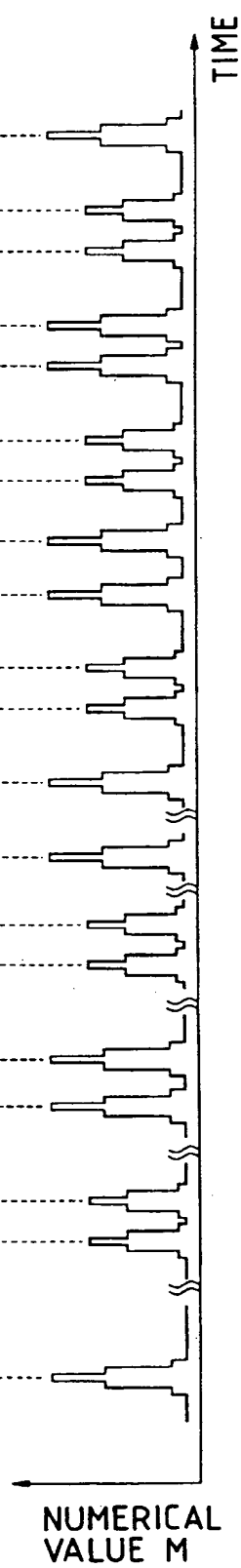


FIG. 11A

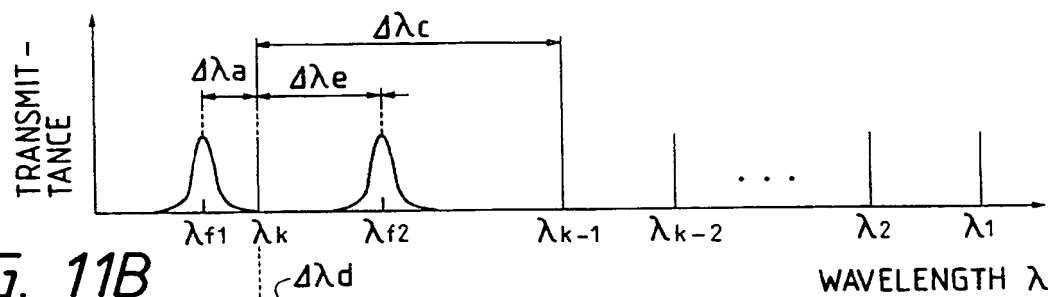


FIG. 11B

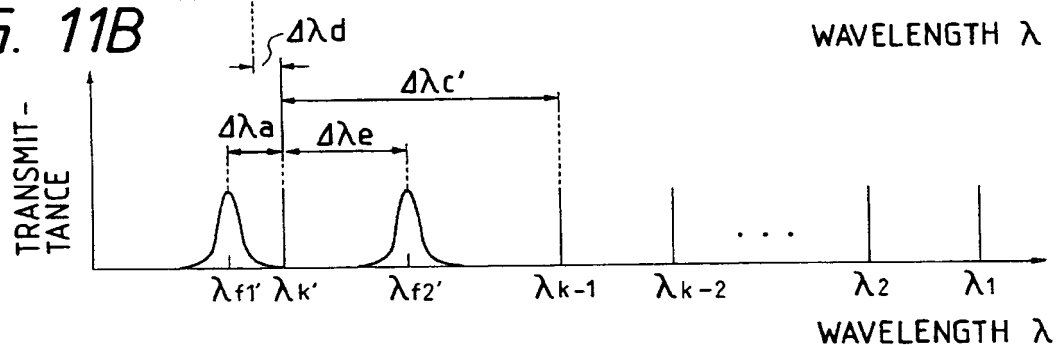


FIG. 11C

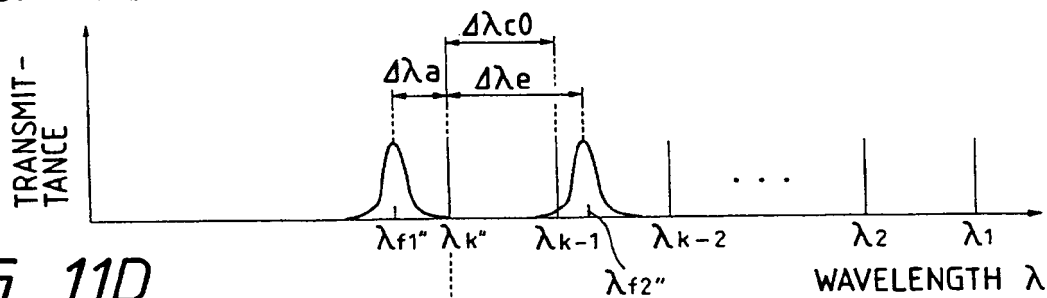


FIG. 11D

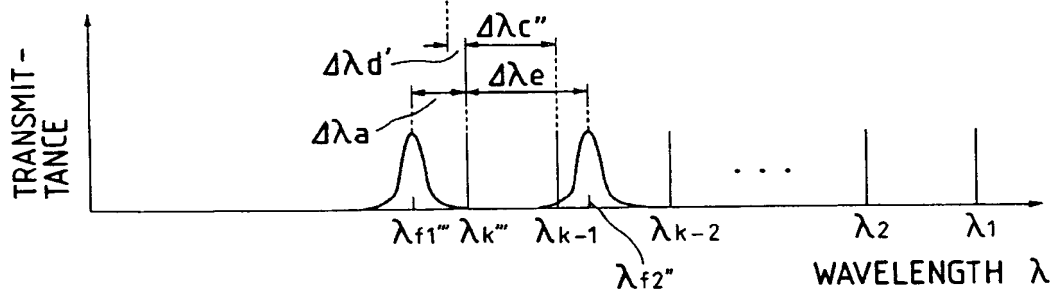


FIG. 12A

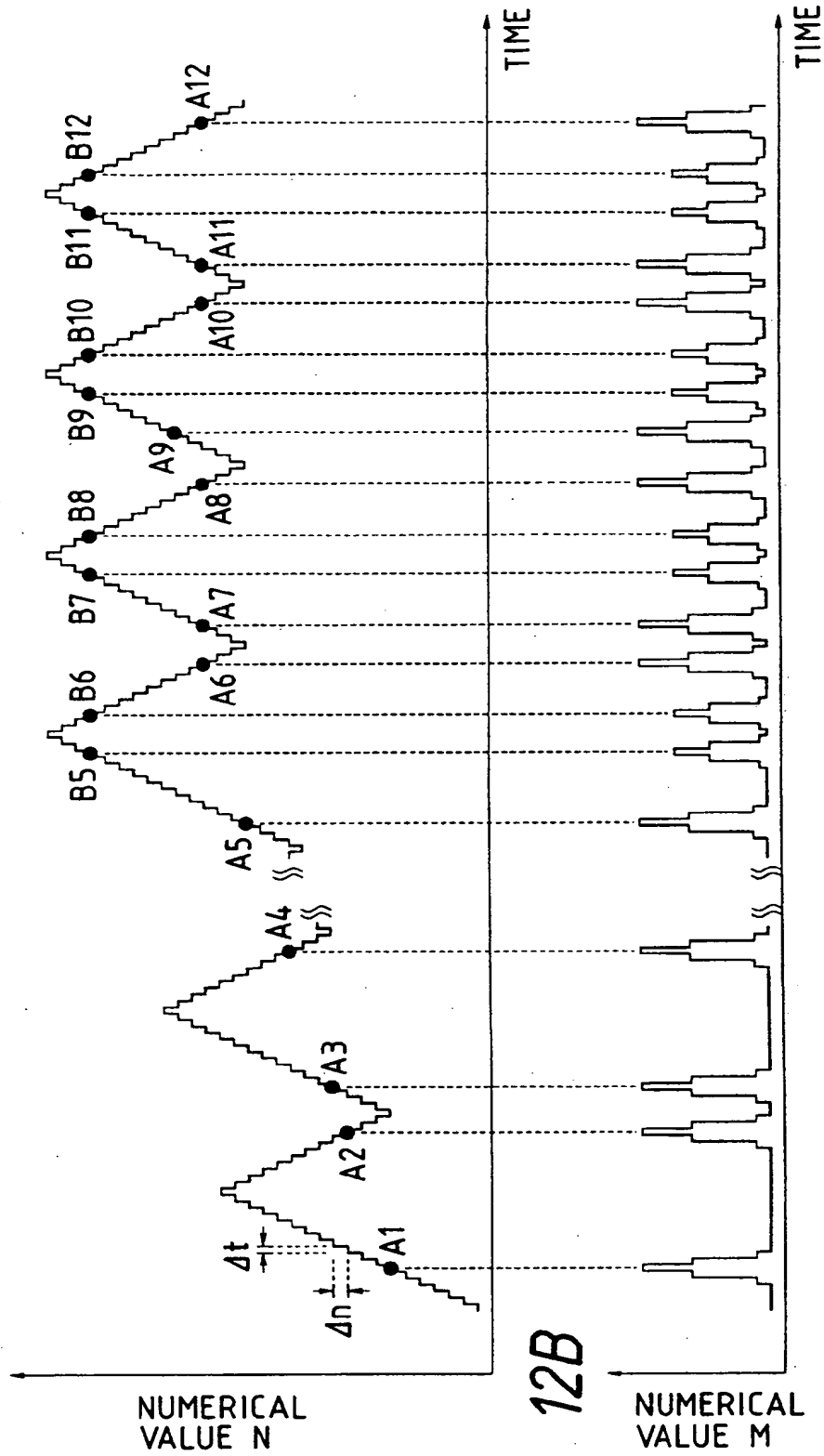


FIG. 12B

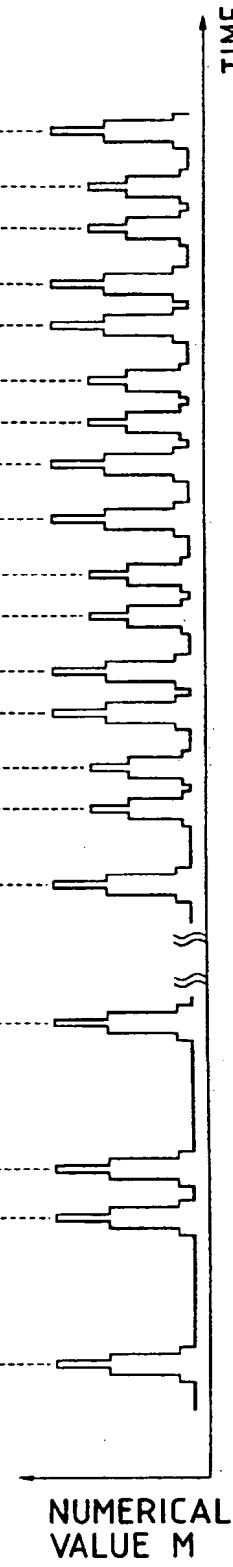


FIG. 13A

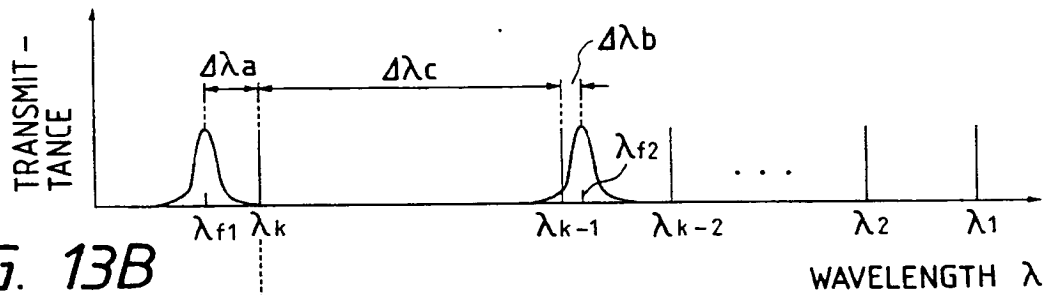


FIG. 13B

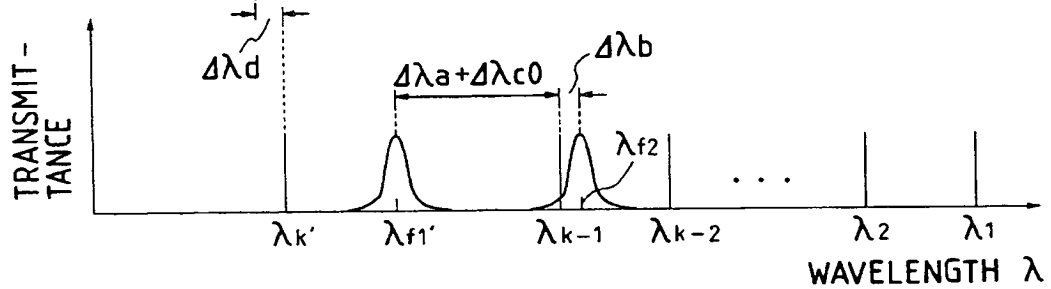


FIG. 13C

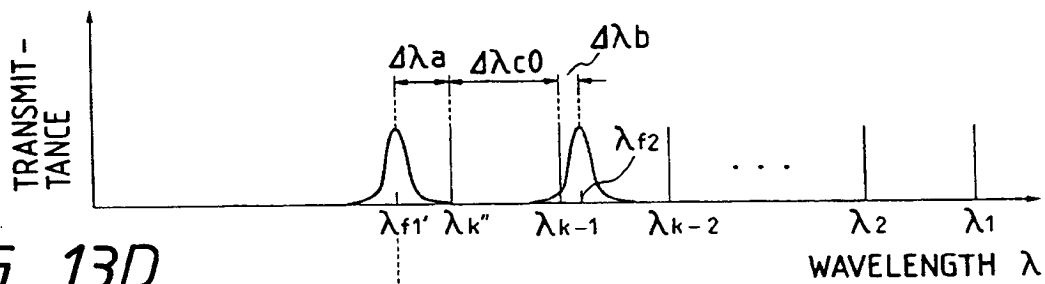


FIG. 13D

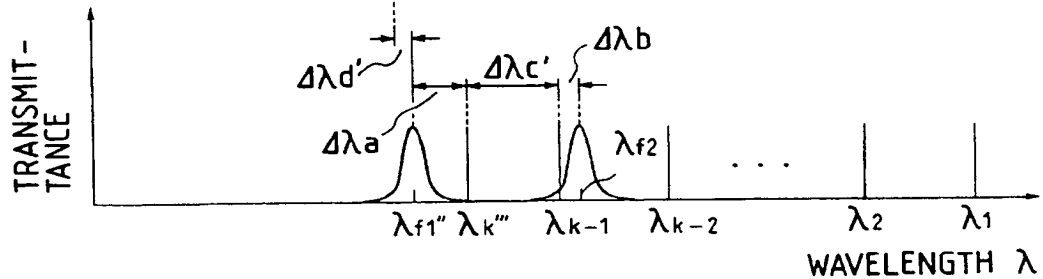


FIG. 14A

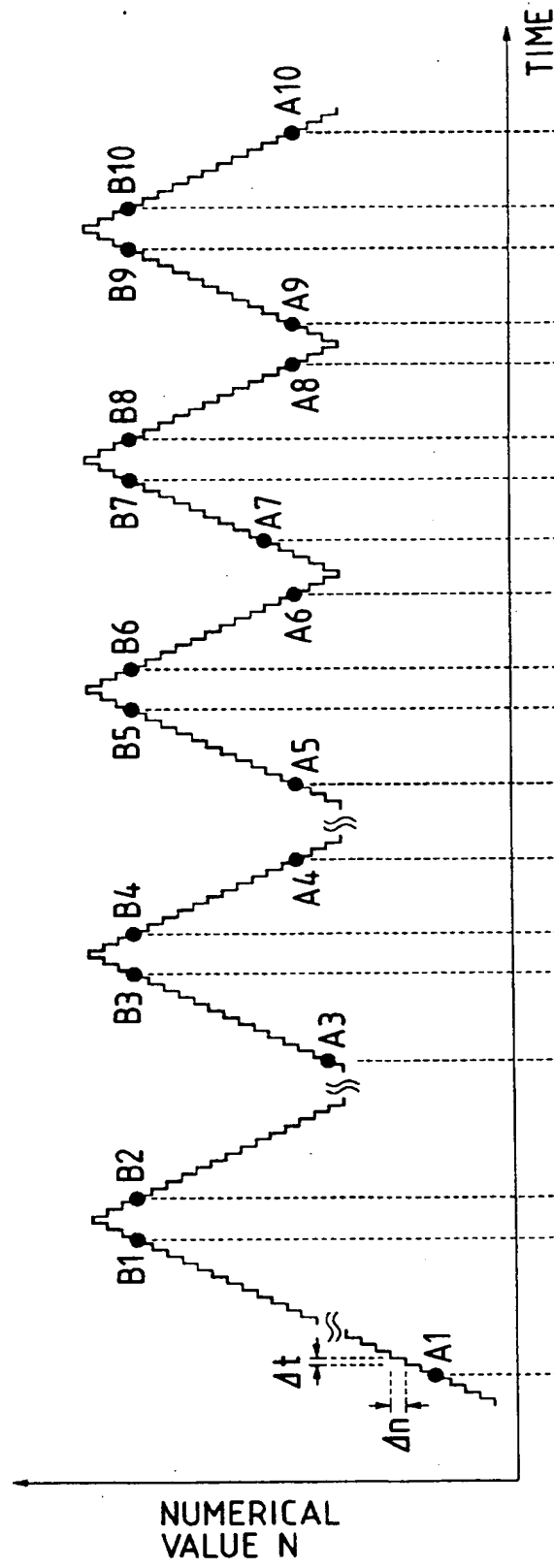


FIG. 14B

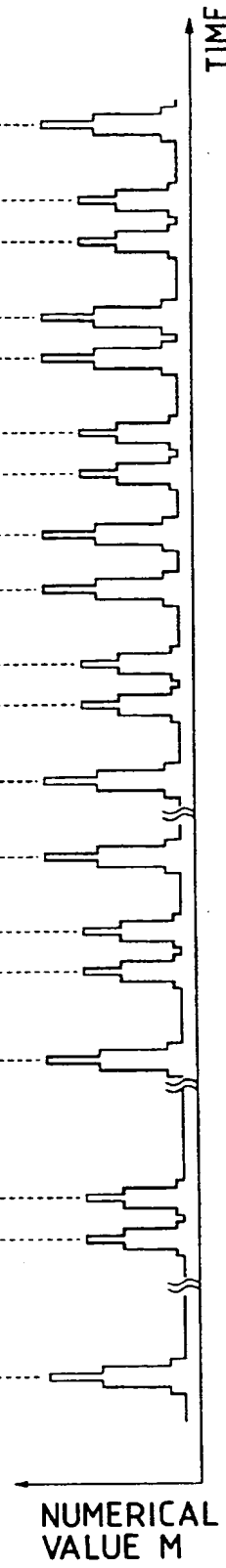


FIG. 15

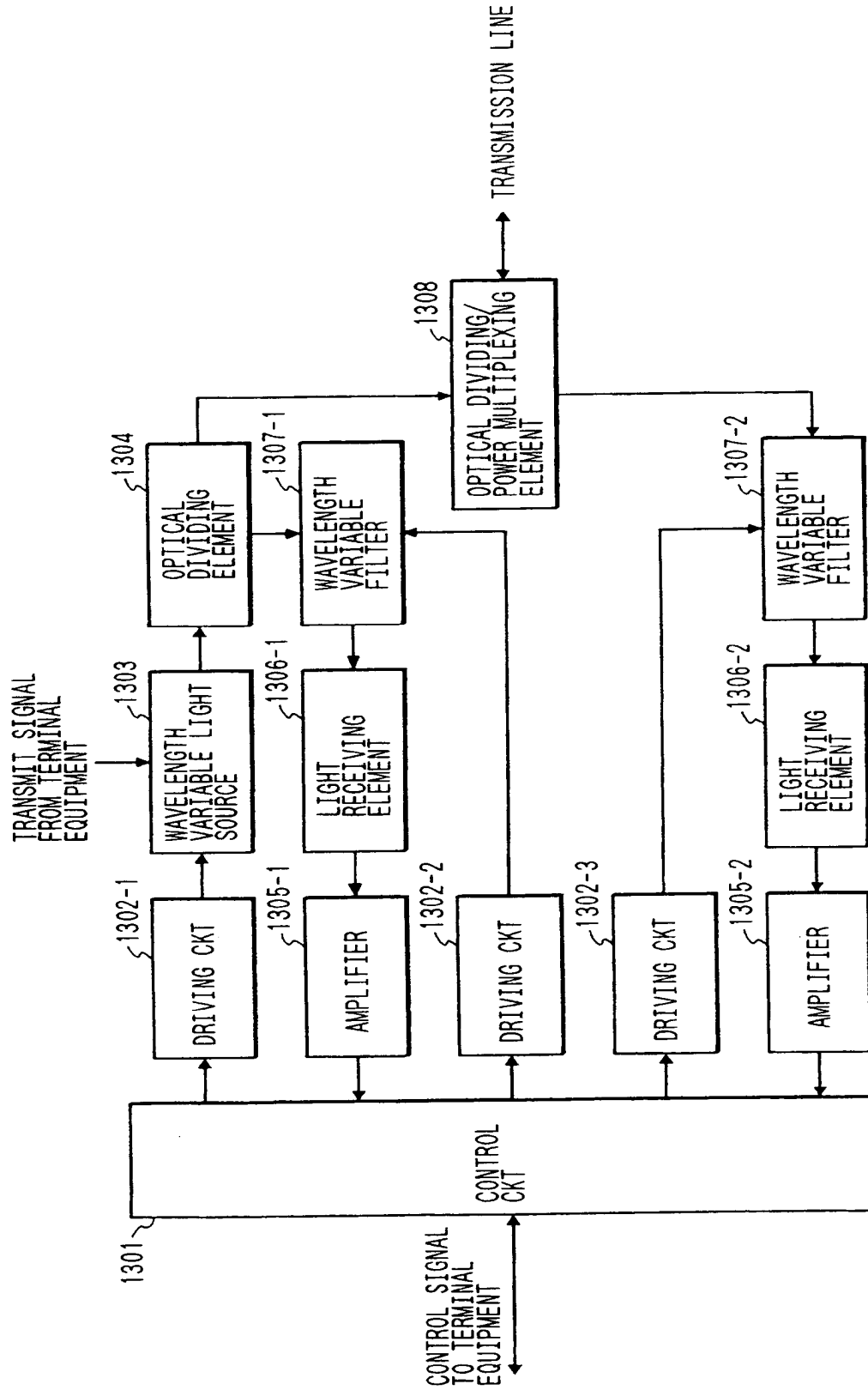
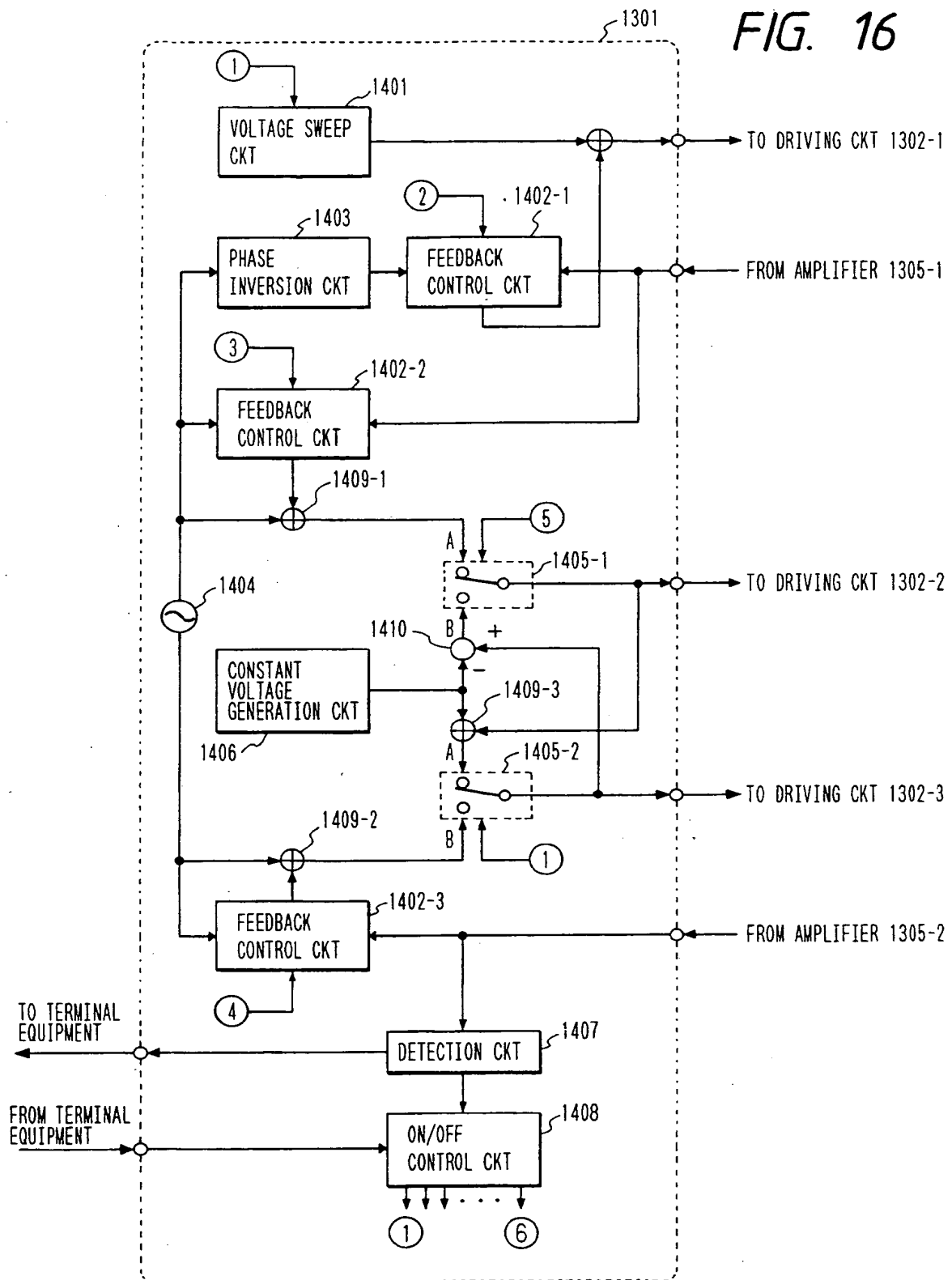


FIG. 16



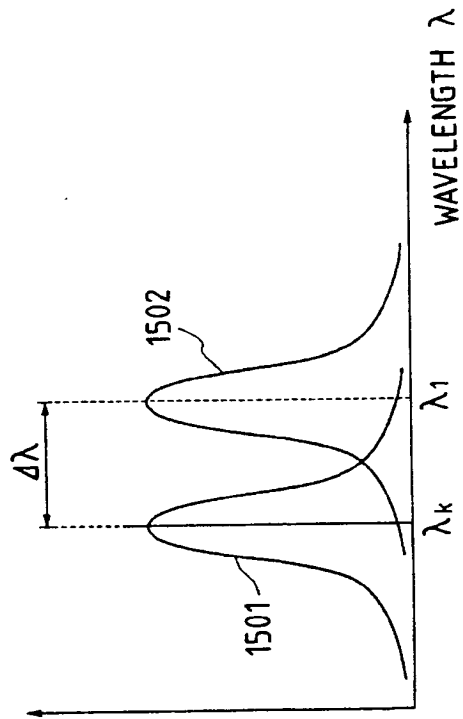


FIG. 17

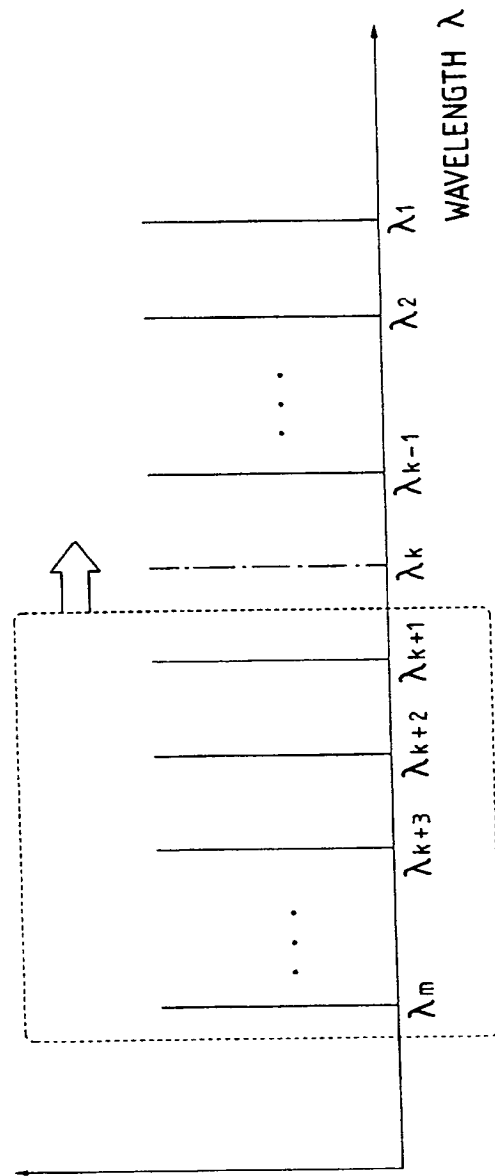


FIG. 19

FIG. 18A

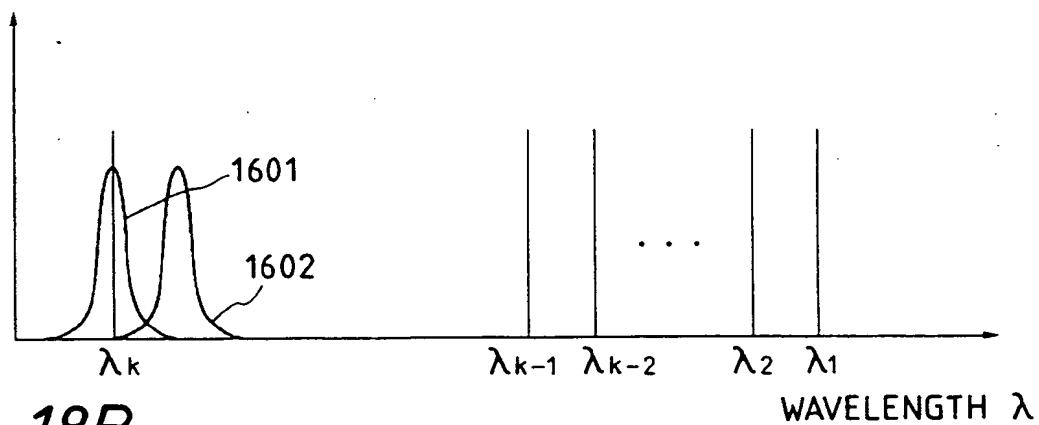


FIG. 18B

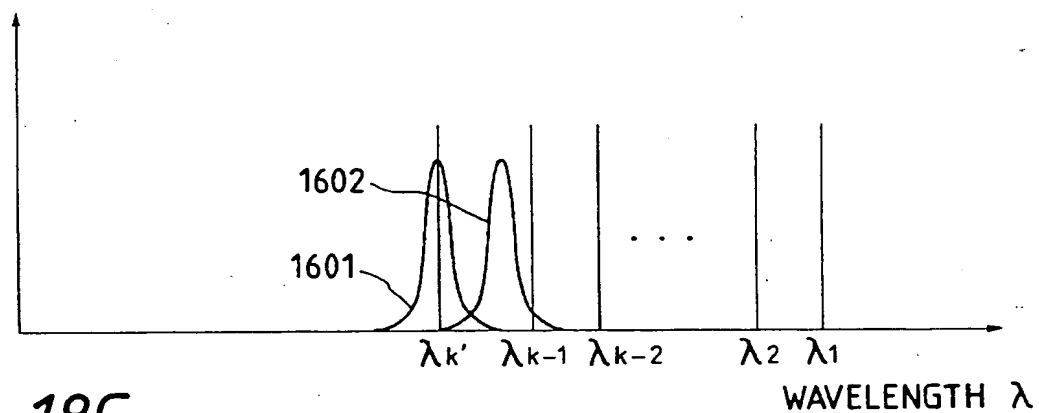


FIG. 18C

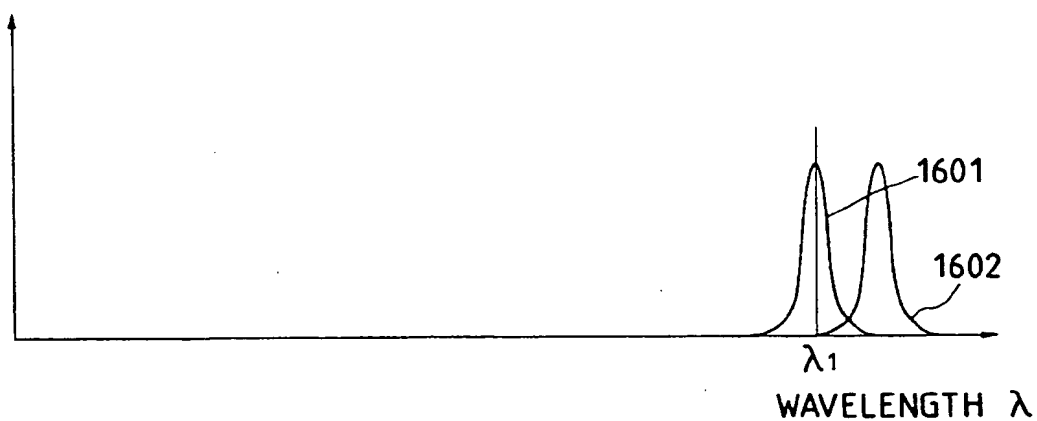


FIG. 20

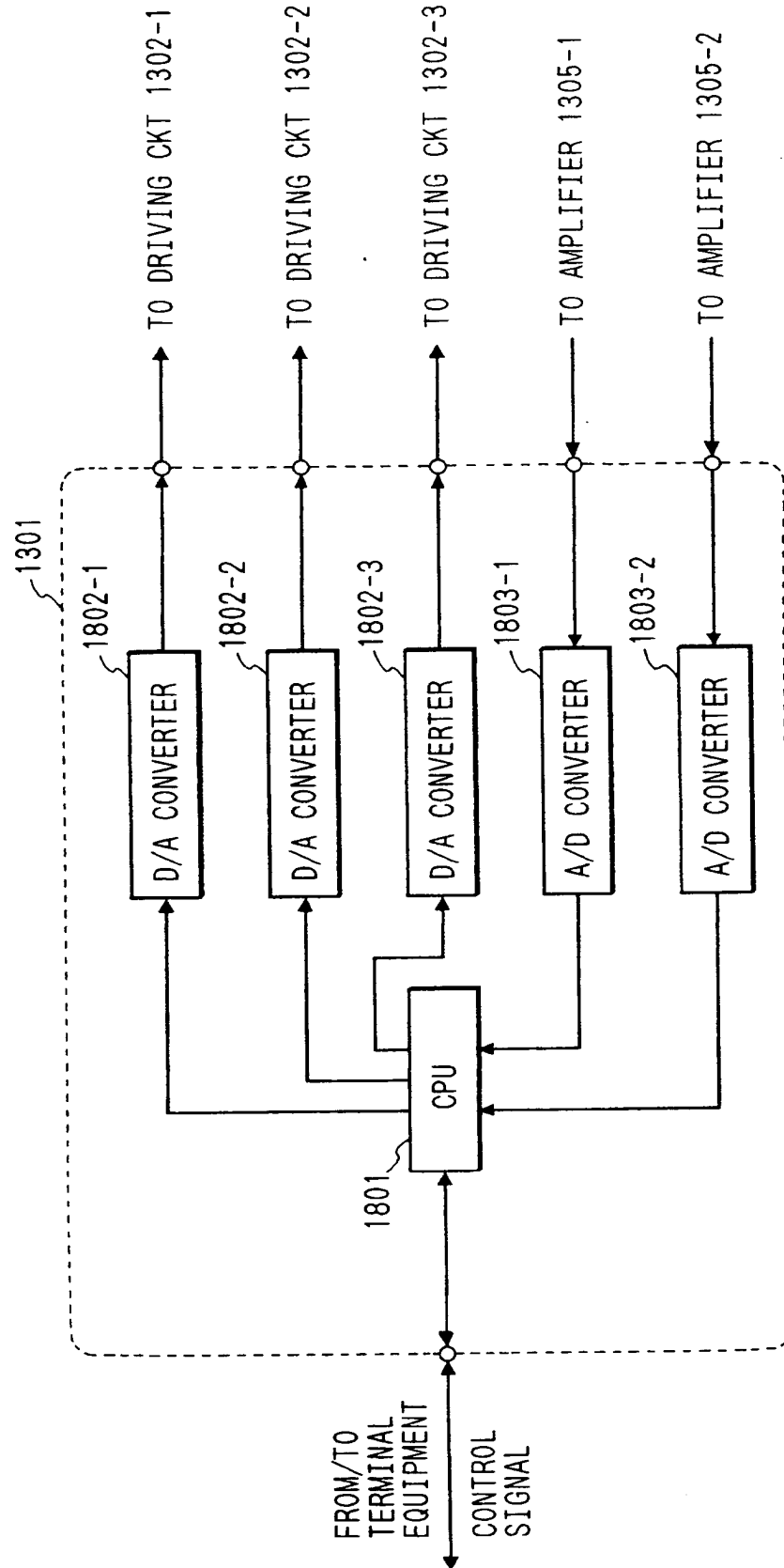


FIG. 21A

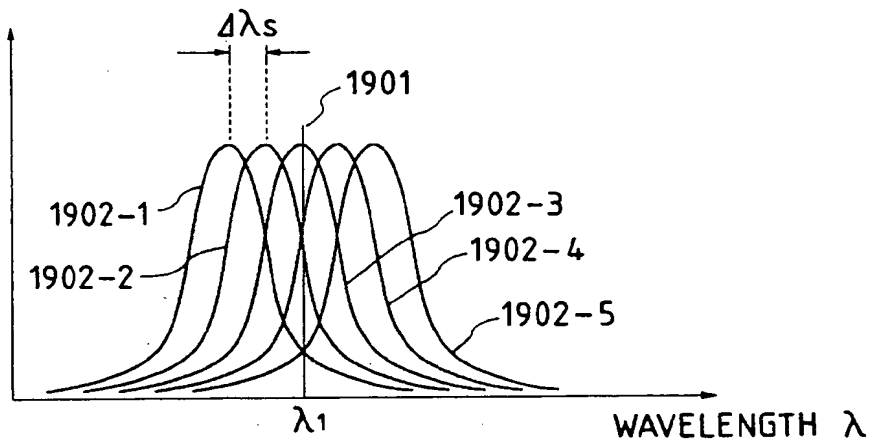


FIG. 21B

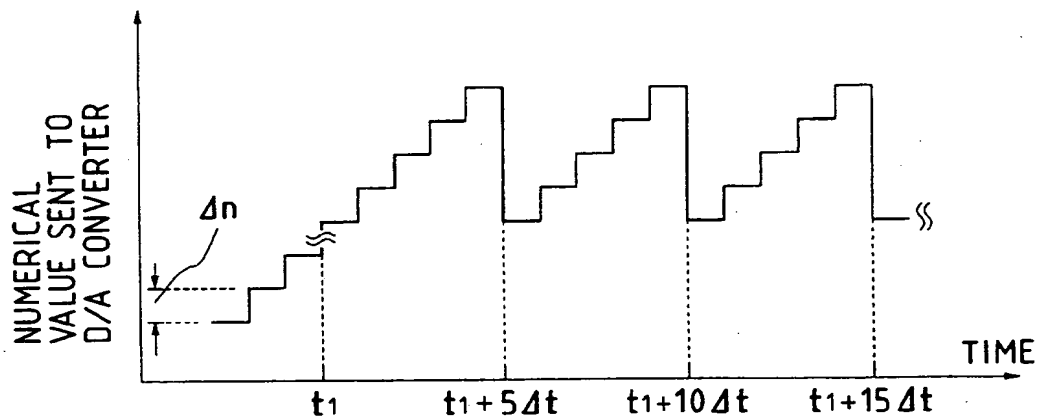


FIG. 21C

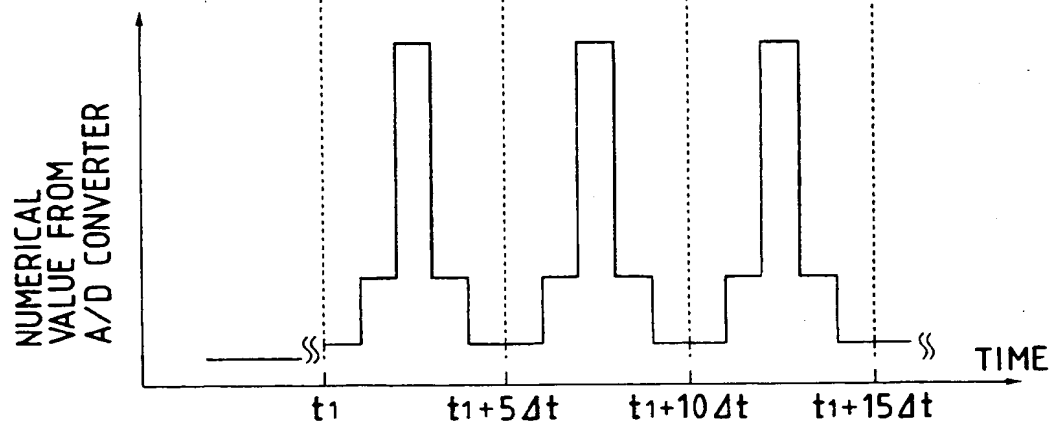


FIG. 22

| DETECTION CKT | NOT DETECT | DETECT |
|------------------|------------|------------|
| ① | SWEEP | STOP SWEEP |
| ② | OFF | ON |
| ③ | ON | OFF |
| ④ | OFF | ON |
| ⑤ | SW A SIDE | SW B SIDE |
| ⑥ | SW A SIDE | SW B SIDE |

(19)



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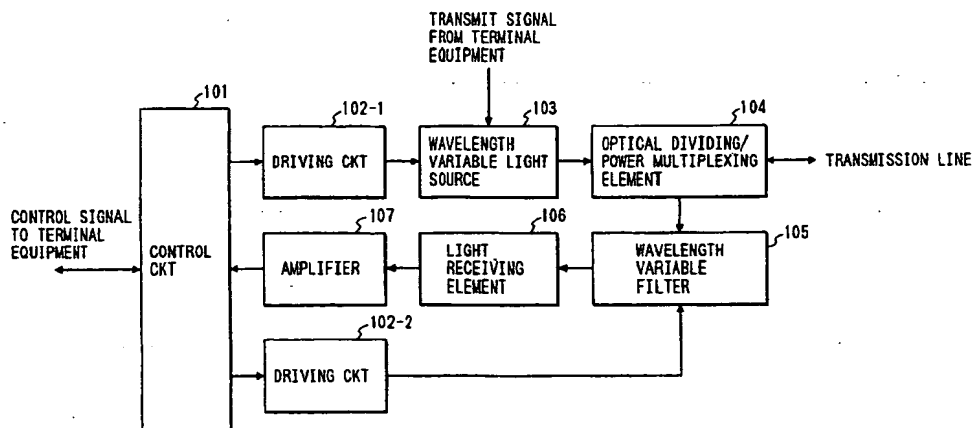
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(54) Wavelength control in a WDM system

(57) In a wavelength-multiplexing communication system, an optical transmitter detects at least either one wavelength of a transmission wavelength of a self optical transmitter and a wavelength adjacent to the transmission wavelength of the self optical transmitter on a wavelength axis either on a longer wavelength side or on a shorter wavelength side than the transmission wavelength of the self optical transmitter by a wave-

length-variable band-pass filter capable of changing a passing wavelength thereof, and controls the transmission wavelength of the self optical transmitter so that a wavelength spacing between the transmission wavelength of the self optical transmitter and the wavelength adjacent thereto may become a predetermined wavelength spacing.

FIG. 3



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EUROPEAN SEARCH REPORT

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| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.6) |
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| | | | TECHNICAL FIELDS SEARCHED (Int.Cl.6) |
| | | | H04J H04B |
| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 25 September 1998 | Examiner Traverso, A |
| CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document | | T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | |

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